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LOCOMOTIVE SPARKS.

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III

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PREFACE.

A STUDY of fuel-losses from locomotives, in the form of sparks, was first made by the author in 1896. From this study the work has gradually been extended to embrace other phases of the spark problem until a considerable amount of data has been collected. Meanwhile, a description of the early work having been published, there were received at the laboratory so many inquiries for information concerning sparks that it has seemed best to summarize and publish the facts now in hand. In selecting data for presentation, an effort has been made to serve students of locomotive performance as well as those who may be concerned with more practical problems. Facts are presented which it is hoped will be found useful to those who have to deal with fuel saving, those who may be interested in the design of spark-arresters or front-end appliances, and those who are concerned with the dangers of accidental fires from sparks.

Acknowledgment is due Messrs. Lewis S. Kinnaird, Alfred R. Kipp, George F. Mug, Charles Ducas, and Jay B. Dill, who, while students at Purdue, were interested in advancing some phase of the whole research. Published results which have been most valuable are those of Messrs. Robert Quayle, Edwin M. Herr, Charles H. Quereau, Herr von Borries, and

Mr. J. Snowden Bell. Individual credit is, so far as practicable, given elsewhere. The author is especially indebted to Mr. Ducas for courteous and generous assistance in the arrangement of data for publication, and in the preparation of illustrations.

W. F. M. G.

Engineering Laboratory, Purdue University,
Lafayette, Ind., October, 1901.

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LOCOMOTIVE SPARKS.

CHAPTER I.

THE LOCOMOTIVE.

1. **Fundamental Conceptions.**—The boiler and engine of a locomotive are similar in their general character to the boiler and engine which go to make up a stationary power-plant. Each exists for the purpose of converting into work the potential energy of fuel. There are differences in the details of mechanism, and in the conditions under which work is performed, but the principles underlying action are the same.

As compared with the locomotive, the stationary plant has an advantage in being fixed in its position. It may be so arranged that all its parts are accessible to attendants, who in doing their work may pass freely from one element to another, and any detail which is better when made large can be given such dimensions as will insure its efficient and otherwise satisfactory performance. In many cases there are no limiting dimensions; the plant may be built as long and as wide and as high as may be desired. It is possible, therefore, to so construct the engines, boilers, and accessory apparatus which go to make up a stationary plant, as to secure any desired degree of efficiency, within limits which are prescribed by the state of the art. If the pulsating sound of escaping steam is objectionable, it can be entirely eliminated by the application of a suitable exhaust-head or muffler. If the presence of a cloud of exhaust-steam is annoying, it may be entirely suppressed by the use of a condenser. If smoke emerging from the top of the stack becomes a nuisance, it may be made to disappear by the use of down-draft furnaces, or by the application of some other form of so-called smoke-consumer. If economy in the use of fuel is an important consideration, small and overworked boilers may be made to give way to others which provide a more liberal allowance of heating-surface. Engines having atmospheric exhaust may give way to condensing engines, simple engines to compounds, and compounds to triple-expansions. The degree of perfection which may be obtained in any or all of these particulars is in fact a matter which is entirely within the choice of the designer, subject only to such limitations as to cost as may be imposed by business considerations.

In passing from stationary power-plants to moving power-plants in the form of locomotives, the designer gives up his freedom of choice with reference to many matters of detail, and finds himself confronted with the necessity of having his work conform to certain general conditions. The work which his boiler and engine are to do must be made to appear in the motion of the plant itself and its attached train. The fact that the whole plant must move across the country with a velocity equal to that attained by the periphery of the stationary engine's fly-wheel, requires the adoption of a cycle which shall serve to transfer the heat-energy of the fuel into work, by as direct a process as practicable.

The stationary plant runs at a fixed speed and usually at a fairly constant load; the locomotive must run at all speeds; it must climb hills, pulling slowly and hard. and it must roll rapidly into valleys, holding back a train which would push it on at still higher speeds.

Important elements must be adapted one to another, and there must be an entire omission of many details which in good practice are considered necessary to the economical working of a stationary plant. The moving parts of a stationary engine work in a substantial frame, which in turn is bolted to a massive foundation, while the frame of a locomotive is suspended by springs from axles carried by wheels which are supported by a yielding and uneven track. The action of the stationary engine can be one of precision, and delicate and precise devices may be embodied in its mechanism which are not at all admissible in the less rigid structure of the locomotive. The stationary engine is protected from the weather and from dust, while the locomotive must give no trouble if worked in rain or snow, or in clouds of dust.

The designer of a locomotive, moreover, is forced to recognize that the machine with which he is concerned constitutes but one of many elements which go to make up the material property of a railroad. The width between the wheels of his engine is prescribed by the gage of the track, and the length of its wheel-base by the curvature of track, the length of turntables, and the dimensions of other facilities at the terminals of the road. The extreme width and height of the machine must come within the limits of clearance which are allowed on either side and above the track, for the locomotive which he designs must pass station-platforms, underneath bridges, and through tunnels.

With such limiting conditions as have been indicated, the locomotive designer has for many years been under the necessity of producing locomotives which will carry greater loads and move at higher speeds than those which have preceded them. Locomotives which could carry twenty cars have given way to newer and larger machines which are capable of carrying forty cars, and trains which used to be pulled at a speed of twenty-five miles an hour must now be carried at fifty miles an hour.

With restraining conditions fixing limits which are absolute, and acting under the influence of a growing demand for increased power, it has been necessary for the locomotive designer to consider economy in the use of fuel as a matter of secondary importance. The problems of reducing noise and of abating smoke have received such attention as the conditions have allowed, but each proposition dealing with these purely secondary questions has of necessity been weighed by him with reference to their effect on the output of power. He knows that smoke from a locomotive can be suppressed, but he also knows that in accomplishing this the firing will be interfered with and the power of the locomotive will be reduced. It is to be noted, also, that the need for power is not one which he has artificially created, but is the outgrowth of a public demand for service. There is in fact no serious defect in the working of the modern locomotive that is not understood and appreciated by the locomotive designer. He allows them to exist because all efforts to overcome them appear to work to the disadvantage of more important characteristics of his machine.

It is but just to add that present-day designers of locomotives have not rested on the achievements of their predecessors but have added thereto a full measure of their own individuality.

The significance of their achievements is to be seen in

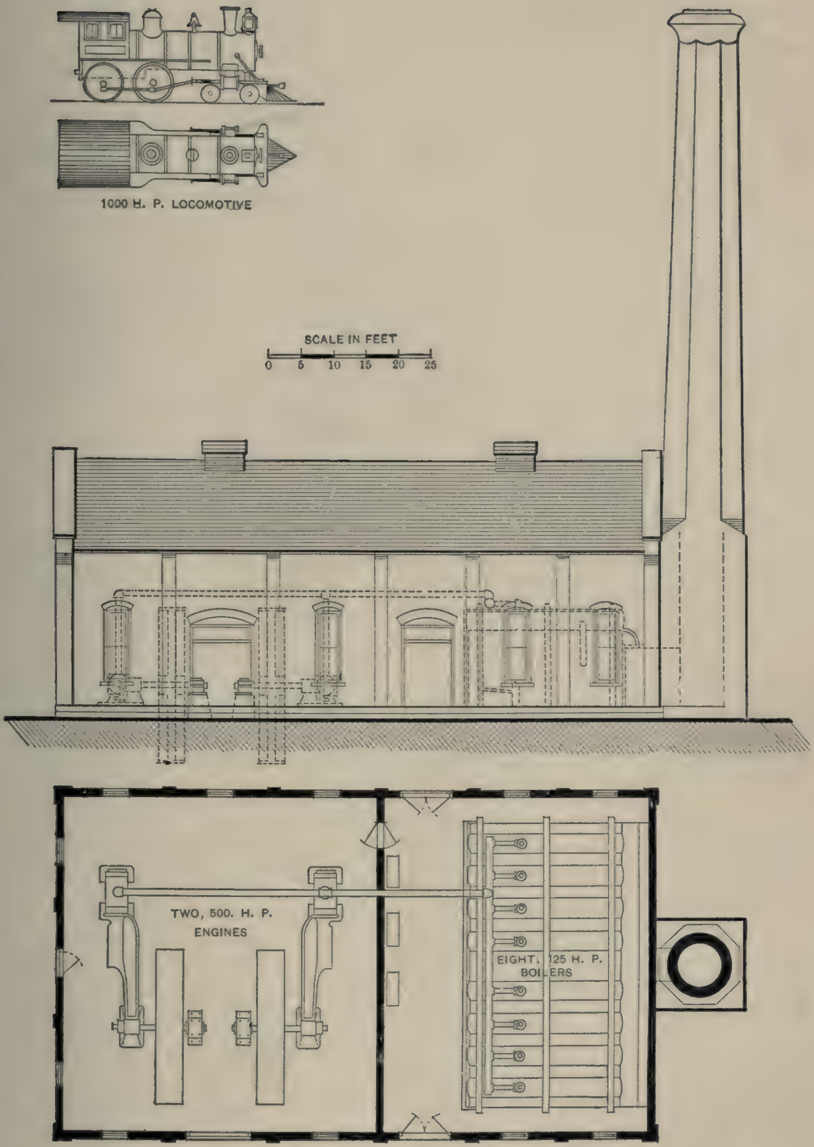
1000 H. P. LOCOMOTIVE
SCALE IN FEET
TWO, 500. H. P. ENGINES
EIGHT, 125 H. P. BOILERS

FIG. 1.

Fig. 1,* which shows two power-plants, each of a thousand horse-power. Both are drawn to the same scale, so that a comparison of the figures discloses their relative dimensions.

The smaller of the two drawings represents a modern locomotive having 2500 feet of heating-surface and 20″ × 24″ cylinders, and consequently quite capable of delivering the power assigned it. The stationary plant represented by the larger drawing is not more liberal in its dimensions than such plants have need to be. It is made up of a suitable building containing a battery of boilers and two slow-speed engines of 500 horse-power each.

The drawings tell their own story. Those of the stationary plant cover an area of paper which is many times greater than that covered by the drawings of the locomotive and yet the power capabilities of the two plants are the same. It is evident that a process which permits the smaller apparatus to equal that of the larger must be one of unusual activity.

When one is inclined to criticize the locomotive because it is somewhat less economical in fuel than the stationary plant, or because it sometimes smokes a little or sends out a few sparks, he should look at these drawings for he will find in them a ready explanation and excuse.

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* From the Railroad Gazette, July 20, 1900.

CHAPTER II.

CONDITIONS CONTROLLING FURNACE-ACTION IN A LOCOMOTIVE.

2. The Locomotive-furnace.—A vertical section of a locomotive-boiler is shown by Fig. 2. The drawing is to be considered somewhat diagrammatical since it does not include minor details.

The furnace or fire-box, as it is often called, is at *A*. It consists of a chamber of steel surrounded at the top and on the sides by the water of the boiler. The bottom of the furnace is fitted with a suitable fire-grate upon which fuel is burned. An opening at the back serves as a fire-door. Below the grate there is ordinarily a sheet-iron ash-pan but this does not appear in the drawing.

The front sheet of the fire-box, known as the tube-sheet, receives the end of tubes which usually are 2 inches in diameter and which extend to the front head of the boiler, *C*. The exterior surfaces of the tubes are in contact with the water of the boiler while their interior surface constitutes a way of escape for the furnace-gases. All the products of combustion resulting from the furnace-action pass from the furnace through the tubes into the front-end or smoke-box, *D*. In passing the tubes the gases from the furnace give up much of their heat to the surrounding water, the tube-surface constituting a very large fraction of the entire heating-surface of the boiler. From the front-end, *D*, the gases from the furnace intermingle with

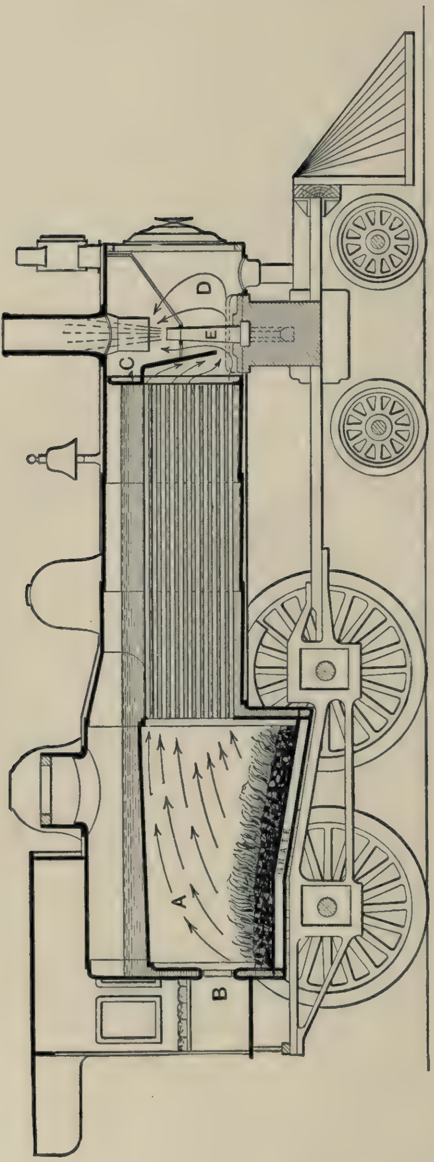

FIG. 2.

the exhaust-steam escaping from the pipe *E*, and are forced up the stack and out into the atmosphere. When the engine is working there is a constant movement of air and heated gases from the grate into the furnace, through the tubes, into the front-end, and up the stack.

3. Rates of Combustion in the Furnace of Locomotives.—It has already been shown that the locomotive is a small machine, when measured by the amount of work demanded of it, and it follows that some or all of its parts are worked to a higher pitch than the similar parts of plants which have more liberal dimensions. This statement is especially true in its application to the locomotive fire-box, for the power developed by locomotives is derived from the fuel it burns, and, other things being equal, whatever operates to increase the amount of coal consumed contributes to an increase of power. With a steady growth in the size of locomotives, there has been a corresponding increase in the amount of coal to be handled, until now it is not uncommon for a modern engine to require as much as 5000 pounds or more for each hour it runs, or 83 pounds a minute. Coal thus required is burned in a fire-box, the dimensions of which are limited by the general arrangement of other important parts of the machine. With large quantities of coal to be burned, in a furnace of small dimensions, the process of combustion is of necessity an active one, as will be seen by the following comparisons.

Soft coal upon a grate in the open air will burn at about the rate of 3 pounds an hour for each square foot of grate-surface. In a heating-stove, under usual conditions of draft, there will be burned about 5 pounds for each foot of grate, and under a stationary boiler connected with a good stack, the rate may increase to 10 or even to 20 pounds per foot of grate. Again, in naval practice with a closed stack-hole and draft forced by blowers, the rate of combustion is occasionally carried as high as 50 pounds per foot of grate per hour, but this value may be accepted as the maximum rate at which fuel is burned for the purpose of generating steam, except in locomotives. Under the lightest service incident to common practice in the narrow fire-boxes of locomotives, the rate is between 50 and 100 pounds, and good practice allows it to rise above 150 pounds, or to three times the rate attained under the conditions of forced draft in naval service. Nowhere are fires urged with greater intensity except in forges or in furnaces employed for metallurgical purposes.

Stating the same fact from a different point of view, it may be said that the grate of a modern locomotive has an area equal to that of a small-sized dining-table. The amount of coal burned on it is so large that if burned in the open air in the form of a bonfire it could only be consumed by making the fire cover an area of a thousand square feet or, say, a grate 10 feet wide and 100 feet long.

4. **Rates of Combustion and Grate-areas.**—The preceding general statements concerning rates of combustion in locomotive-furnaces may be accepted as fairly representative of conditions prevailing in good American practice. In order that a fuller view may be had of the subject, it will be well to consider for a moment what are the conditions governing the rates of combustion, and the expedients which have been resorted to by the American designer in his efforts to keep them within reasonable limits.

As already indicated, the intensity of the burning is well expressed by the pounds of coal consumed per unit area of grate. When 20 pounds of coal are burned per foot of grate-surface each hour, the process of combustion is double in its intensity that which attends the burning of 10 pounds on the same area in the same time. It is evident, also, that with a given total weight of coal to be burned, the rate of combustion will be inversely proportional to the area of the grate; that is, as the grate is increased in size, the rate of combustion will be diminished. In their desire to keep the rate of combustion within reasonable limits, locomotive designers have continually sought means whereby the grate might be enlarged.

Previous to 1890 practically all American locomotives were built along the same general lines The fire-box extended down between the side-frames, while the axle of the forward drivers passed across in front and that of the rear drivers behind. Under these conditions, the maximum width of the grate was between 34 and 35 inches. It could not be made materially greater without widening the gage of the track. The length of the grate was determined by the spacing of the two axles already referred to, and which were ordinarily 8 feet apart, the feeling being that the coupling-rods by which the drivers of each side are connected, one with another, should not be longer than was necessary to span this distance. With these limitations, after allowing clearance for axles and eccentrics, the maximum length of the grate could be about 75 inches. A width of 35 inches and a length of 75 inches gives an area of about 18 feet. For a time it appeared that this must remain the maximum size of grate. Gradually, however, side-rods were lengthend to 8½ and even 9 feet, with a corresponding gain in length of grate. At the same time, also, there began the practice of sloping the grate and raising the centre line of the whole boiler. By these means the back of the grate was brought sufficiently high to pass over the rear axles, permitting the fire-box to extend rearward an indefinite distance. The practical limit to the length of grate under these conditions was, however, found to be the distance from the fire-door at which a fireman could spread coal over the forward end of the grate—a distance which could not be allowed to exceed 10 feet; and in many cases the maximum length was fixed at 9 feet. By these means the grate-area was made to approach 30 square feet.

The next great step was taken when the boiler was still further raised, the depth of the fire-box diminished, and the form of the frame modified so that the fire-box could rest on top of the frames instead of extending between them. This enabled the width of the grate to be increased by an amount equal to the sum of the width of the two side-frames which is from 8 to 10 inches. This change permitted an extension of grate-area to about 36 feet but in the case of the eight-wheeled type of engine no further increase of area can be had by widening the fire-box which must still come between the drivers.

Further extensions in grate-area can, however, be had by the adoption of such a modification in wheel arrangement as will permit the fire-box to be extended sidewise beyond the gage of the track. Such exceptional designs have from time to time appeared, the most noteworthy being the Wootten boiler, having a shallow fire-box extending out over the wheels, giving an area of from 60 to 85 square feet. To allow the use of so wide a structure, the coupled drivers are brought close together and placed ahead of the fire-box, the rear of the engine being carried on a pair of small trailing wheels, over the top of which the fire-box is free to extend. Locomotives having such a wheel arrangement have come to be known as of the Atlantic type.

The Wootten boiler was originally designed for burning fine anthracite coal which needs to be spread very thin and permitted to burn at a comparatively low rate. As the supply of such coal is not general, these engines have been confined to a limited area within which the fine anthracite coal is to be had. It is to be noted that the Atlantic type of engine is not adapted to all classes of service; also, that the Wootten boiler is serviceable only in connection with the peculiar fuel which it is designed to use. When tried with a lighter bituminous coal, such as must be used in our Western States, it was found impossible for a single fireman to keep the grate covered, with the result that steam-pressure could not be maintained. The fact to be emphasized is that the existence of the Wootten boiler is not in itself evidence that rates of combustion in all locomotives using all classes of fuel can be made low.

There are now, in 1900, evidences that the essential features of the Atlantic type engine and of a modified form of the Wootten boiler will be adopted in locomotives designed for burning soft coal. Several roads of the Middle and Western States now have wide fire-boxes in service which have from 40 to 50 feet of grate-area. This is as large a grate-area as can well be fired with soft coal by one man.

In spite of the gradual increase in grate-area which has been noted, rates of combustion per unit of grate-area have not greatly declined in recent years. Such progress as may have been made in securing enlarged grates has done but little more than to keep pace with the increased amounts of fuel which, as engines have increased in power, are required to be burned. What this rate is required to be for the development of varying amounts of power is well shown by results obtained in a series of tests made upon the Purdue experimental locomotive (see Appendix). This locomotive is now to be regarded as one of rather small size. It weighs 85,000 pounds, has 17″ × 24″ cylinders and during the tests was run at a speed of 35 miles an hour with a wide-open throttle and a steam-pressure of 130 pounds, conditions and results as to coal burned, all of which may be accepted as within the limits of good practice, being as follows:

Cut-off.	Horse-power.	Total Pounds Coal per Hour.	Coal per Sq. Ft. of Grate per hour.
6″	300	1262	72
8″	434	1978	113
10.5″	495	3133	179

5. Draft.—The passage of air through a mass of burning fuel constitutes what is usually known as "draft." It is by the action of the draft that the process of combustion is stimulated. If the draft is weak, the rate of combustion is low; if strong, the rate of combustion becomes high. The draft is, in fact, in all cases the regulator by means of which the rate of combustion is controlled. It has already been shown that the rate of combustion in a locomotive is abnormally high and it follows that the draft must be correspondingly strong.

In a locomotive the draft results from the action of the exhaust-steam which, after doing its work in the cylinders of the engine, is made to pass upward through the smoke-box and out by the stack in such a manner and at such velocity as will induce a current in the smoke-box gases through which it passes. In this manner the exhaust-jet serves not only to discharge the smoke-box gases, but it draws upon them with sufficient vigor to produce a partial vacuum in the front-end. This condition prevails whenever the engine is in action.

With a pressure in the front-end which is less than that of the atmosphere, there is a constant tendency for air to pass from the atmosphere to the front-end. The only avenue is by way of the ash-pan through the burning fuel, into the furnace, and thence on through the tubes. The activity of this movement will evidently depend upon the difference between the atmospheric pressure and the pressure in the front-end, and it has become the practice to measure the intensity of the draft-action in terms of this difference of pressure. The unit of measure is usually taken to be the displacement of a column of water 1 inch high, equivalent to 0.04 pound per square inch, or 5.2 pounds per square foot. The draft employed in boilers of stationary plants with good stacks is from 0.1 to 1.4 inches of water. In naval practice, with closed stack-hole and forced draft, it is from 1 to 4 inches, while in a locomotive burning bituminous coal, it ranges from 3 to 10 inches, depending upon the service, character of the fuel, and the condition of the fire. Under ordinary conditions of service it does not often fall below 6 inches, which is equivalent to a difference of pressure between that of the atmosphere and that of the gases of the front-end of 31 pounds per square foot. Such a draft is quite comparable in intensity with that employed to urge the fire of a blacksmith's forge, though in the latter case the area affected is small, while in the former case, the full area of the grate is affected. The relation between draft and rate of combustion for the experimental locomotive of Purdue University is as follows:

Reduction of Pressure in Front-end as Compared with Pressure of Atmosphere.		Pounds of Coal per Square Foot of Grate per Hour.	
Inches of Water.	Pounds per Sq. Ft.	Brazil (Ind.) Block.	New River.
2.00	10.40	64.14	53.00
3.34	17.37	113.46	81.00
4.30	22.36	146.62	100.00

CHAPTER III.

CINDERS AND SPARKS.

6. How Cinders are Made.—The activity which characterizes the process that goes on in the fire-box of locomotives has already been described. That required rates of combustion may be maintained, the air-currents passing through the fire need to be very strong. Air enters through the grate, mingles for an instant with the combustible properties of the fuel, the fuel burns, and the products of combustion are as quickly drawn away from the fire-box, through the tubes to the front end, and thence forced up the stack and into the atmosphere. The whole passage from the grate, through the fire-box, and into the tubes is as in a twinkle of an eye.

The layer of incandescent fuel often dances on the in-rushing currents of air and if by chance some portions become thinner than others, individual coals of considerable size are tossed far above the general level of the fire, settling back and awaiting for an instant a new impulse to send them up again, responding to the action of the exhaust, just as apples keep in air in response to the toss of a boy's hand. If the spot continues to become thinner, the strength of the draft will after a time overcome the weight of the fuel, which floats away bodily, leaving a "hole" in the fire with the bare grate at the bottom.

In the midst of such conditions as these, sparks are born. Light particles of coal, unless well cemented together by water when thrown into the furnace, never reach the grate but ignite in the flame of the furnace and partially consumed are borne into the tubes. When a friable coal is used, the lumps on the grate, breaking up under the action of heat, give rise to many small fragments which prove too light to keep their place with the more solid masses of the fire. These also fly into the tubes. Much of the ash which results from the combustion of fuel on the grate, and which in a stationary boiler would drop through to the ash-pan is, in a locomotive-boiler, caught up by the draft and carried into the tubes along with the incandescent coke to which reference has already been made. It is in this manner that the procession of cinders is formed. Every particle which enters the tubes at the fire-box end is ordinarily carried through into the smoke-box. Here some are entrapped. In the smoke-box they gradually cool, the exclusion of outside air preventing the combustible portion from burning. At the end of the run they are removed. The remainder, after being baffled and knocked about by obstacles set in their path, and greatly lowered in temperature by contact with escaping steam, are thrown out from the top of the stack.

7. Front-end Cinders.—It will be seen that the solid material entering the tubes from the fire-box has either the form of living coal or that of ash. By the time it reaches the front-end the coal has become coke. The mixture of finely divided coke and ash which finds its way into the smoke-box is indiscriminately referred to as sparks, cinders, smoke-box cinders, and *front-end cinders*, these terms applying to the material while it is within the front-end and, also, after it is removed therefrom and put to various uses. Without attempting to discuss the reason underlying the use of these various terms, that of "front-end cinders" will be employed for the purpose of the present text.

8. Sparks.—Of all the solid particles which pass through the tubes and which by convention are to be called front-end cinders, a portion passes out of the top of the stack. Such particles are commonly spoken of as "sparks" or "cinders." For the present purpose they will be called *sparks*. It should be noted that this term is adopted merely as a definition; it is not strictly descriptive. The cinders which escape from the front-end and become sparks retain all the characteristics of front-end cinders. Some are composed entirely of ash. Others are of coke which, in their passage of the front-end, have been hammered against plates and immersed in steam until they are entirely deprived of fire, and are as incapable of doing damage by fire as the ash itself. All such sparks are commonly referred to as "dead sparks." Still others, constituting a very small proportion of the whole, escape at a temperature sufficiently high to glow in the dark, and of these it sometimes happens, where very light fuel is used, that a few flame. But flaming sparks are of rare occurrence.

9. The Conditions Affecting the Production of Cinders and Sparks.—The production of front-end cinders and sparks depends upon many variable factors. As has been shown, the most active agent is to be found in the action of the draft, but the condition of the fire, manner of firing, and the character of the fuel, all have their influence. Fine coal, if fired dry, results in more cinders and sparks than when well wetted before firing. A light friable coal, even though thrown upon the grate in large-sized lumps, will often, under the action of heat, quickly break into smaller fragments, many of which are sufficiently small to be caught up by the draft. A good quality of bituminous coal which holds together well in burning will give off very few live sparks, and the sparks of anthracite coal are practically nothing but ash.

It will be evident that conditions favorable to the production of cinders and sparks are, under normal conditions of working, always present; that this fact is not the outcome of improper design nor of any failure to appreciate the disadvantages they involve on the part of those responsible for the proper operation of locomotives; but they exist as a necessary consequence of the exactions of service and in spite of the efforts of skillful men who have lived and worked since the day of Stephenson to overcome them.

10. Experiments to Determine the Extent of Spark-losses.—Such experiments were first made in the laboratory of Purdue University. The locomotive of this laboratory is so mounted that while its machinery may be run at any speed and under any condition of load, the locomotive as a whole maintains a fixed position. It is possible, therefore, in the case of this locomotive to work about the top of the stack in a manner which would be wholly inadmissible in connection with a locomotive on the road.

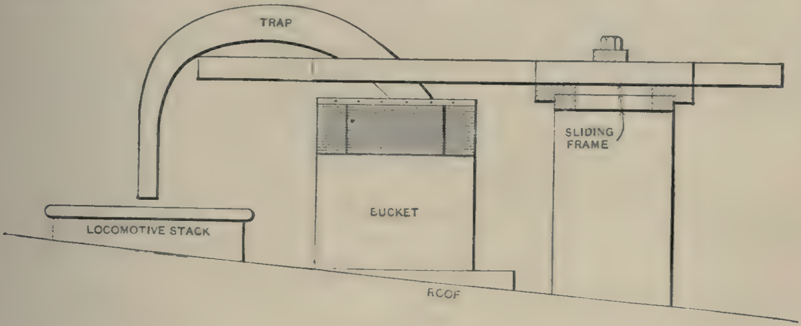

FIG. 3.

The apparatus employed in determining the extent of spark-losses is shown by Fig 3.* It consists of an inverted U tube of galvanized iron, securely fastened to a movable frame, by means of which the tip, which constitutes one extremity of the tube, can be projected across the top of the locomotive smoke-stack. The outer end of the tube may thus be made completely to intercept a portion of the stream issuing from the stack, and the continuous action of this stream is sufficient to drive the intercepted portion through the tube and out at the other end. The gases passing the tube bear the sparks on their current, and they are collected in a bucket set to entrap them. Reference marks upon the sliding and the fixed frames permit the tube to be placed in definite locations relative to the centre of the stack. This device, when in service, catches everything excepting the lightest soot, which is allowed to escape unaccounted for.

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* From a paper on "The Effect of High Rates of Combustion upon the Efficiency of Locomotive-boilers."—New York Railway Club, Sept., 1896.

After assuming the cross-section of the stream issuing from the stack to be cut up, by a series of concentric circles, into one circular and several annular areas, as shown by Fig. 4, the small end of the U tube was placed in the position marked *I* and held there for thirty minutes, the sparks collected during this interval being credited to this position. The tube was

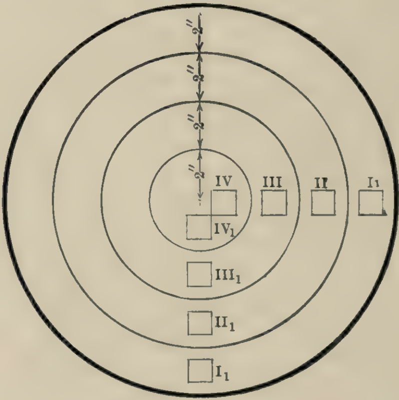

FIG. 4.

then moved to the position II, where it remained for another period of thirty minutes. In like manner, it was made to occupy, successively, the positions III and IV, and also the positions I_1, II_1, III_1, and IV_1, the weight of sparks caught during each interval being credited to the corresponding position occupied by the small end of the tube. This end of the tube had an area of 1 square inch, and it was assumed that the average weight of sparks passing the tube while in the positions I and I_1 would be the same as that passing every square inch in the annular space in which these positions are located. For example, the outer annular area, in which I and I_1 are located, contains 88 square inches. If, in half an hour, 0.5 pound was collected by the tube in the position I, and in another half hour 0.3 pound was collected from the position I_1, the sum of these two weights, or 0.8 pound, collected during a period of one hour would be the average weight per square inch per hour collected from the two positions, and the weight for the whole outside annular area would be 0.8 times 88, the number of square inches, or 70.4 pounds per hour. A similar experiment and calculation gave the weight per hour delivered by each of the other annular areas II and III, and by the circular area IV. The sum of these separate determinations was assumed to be the total weight of sparks per hour delivered from the stack.

11. **Size of Front-end Cinders and of Sparks.**—So far as mechanical arrangements are concerned, there is nothing to limit the size of front-end cinders except the diameter of the tubes through which they must pass. These generally have a clear diameter of about 1¾ inches. The dimensions of front-end cinders cannot exceed and seldom reach such limits. The active conditions affecting their size are to be found in the strength of the draft and the character of the fuel.

Sparks discharged from the stack are as a rule much smaller than front-end cinders. After passing the tubes these are met by a complicated series of obstructions which serve to break them up and to stop all which exceed certain fixed limits in size. What these retarding agents are, it is the province of another chapter to explain. In general, it may be said of sparks, as of front-end cinders, that their size depends upon the draft and the character of the fuel.

An exhibit of typical cinders and sparks is presented as Figs. 5 and 6. In each case the pile *A* is made up of sparks emitted from the top of the stack, collected in the manner already described, while the pile *B* is composed of cinders taken from the front-end after a run. For purposes of comparison, a pile of buckshot (*C*) is added, the diameter of the individual shot being $\frac{5}{16}$ of an inch. The sparks and cinders making up Fig. 5 represent conditions of heavy running. They were obtained during a test for which the draft was represented by 7 inches of water and the rate of combustion was 221 pounds of coal per foot of grate per hour. Fig. 6 represents conditions of light running, the materials shown having been obtained during a test for which the draft was represented by 3 inches of water and the rate of combustion was 84 pounds of coal per foot of grate per hour. The coal was Brazil block and the tests were made on the experimental plant of Purdue University. The materials shown on both figures may be accepted as representative of all that accumulated during tests of several hours' duration, and as extreme conditions are represented, it is but fair to presume that the largest sparks which are likely to be given off from the stack by an engine in good condition are those shown by *A*, Fig. 5, and that under lighter conditions of running they may not run larger than those shown by *A*, Fig. 6.

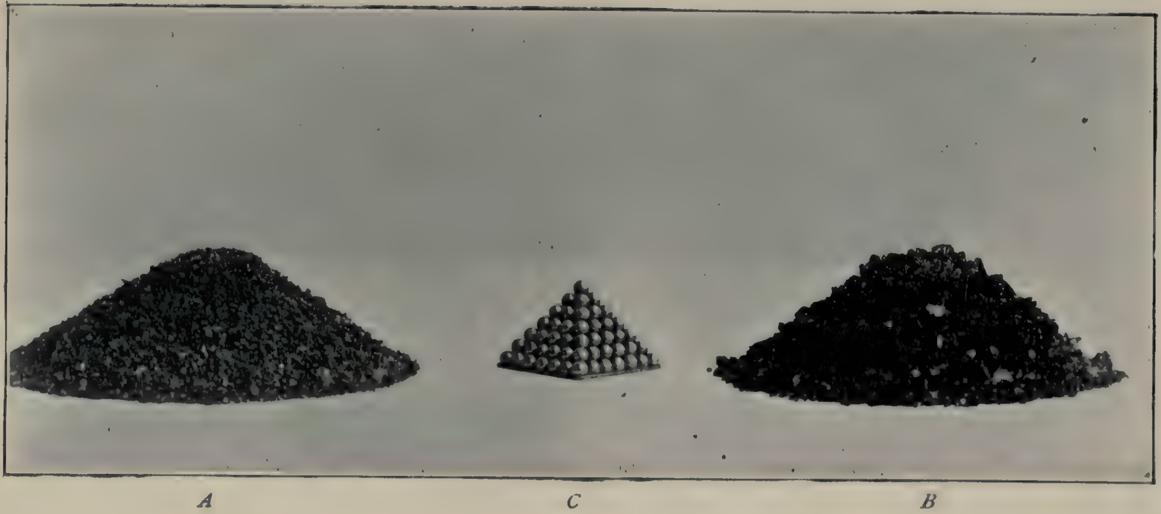

FIG. 5.

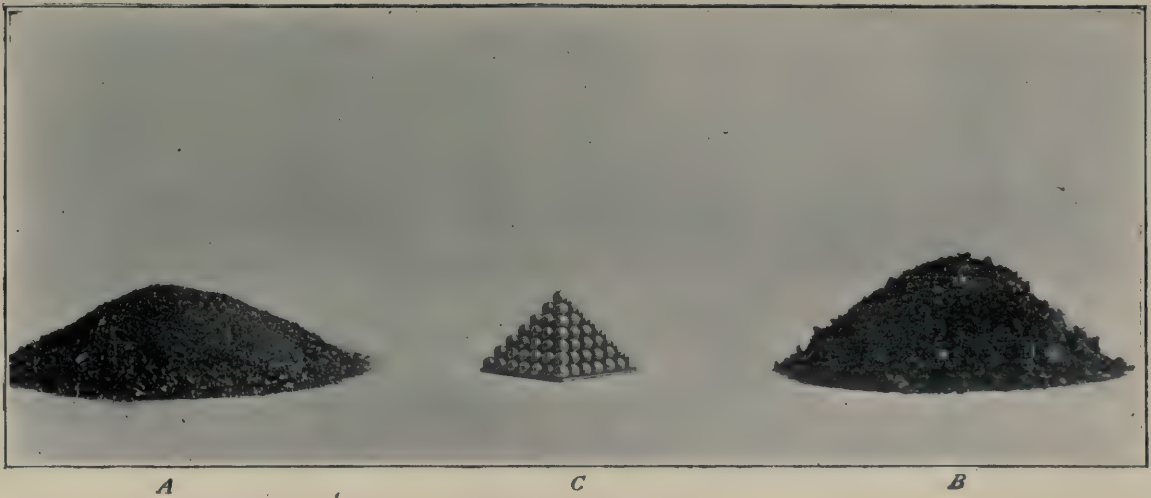

FIG. 6.

12. The Loss of Fuel by Cinders and Sparks.—The total cinder- and spark -loss for any given period is found by ascertaining the weight of the solid material which accumulates in the front-end and the weight which is discharged from the top of the stack. Weighings of the front-end cinders are readily made at the end of a run and the weight of sparks passing out of the stack may be determined by the method already described.

Results of an investigation thus made are presented in Table I.

TABLE I.

SHOWING WEIGHT OF CINDERS AND SPARKS FROM THE PURDUE LOCOMOTIVE, SCHENECTADY NO. 1, WHEN USING BRAZIL BLOCK COAL.

Number of Test. I.	Speed in Miles per Hour. II.	Position of Reverse Lever. Notches forward of Centre. III.	Draft in Inches of Water. IV.	Total Pounds of Coal Fired per Hour. V.	Pounds of Coal Fired per Square Foot of Grate-surface per Hour. VI.	Pounds of Sparks Passing out of Stack per Hour. VII.	Pounds of Cinders Caught in Front end per Hour. VIII.	Total Pounds of Cinders and Sparks per Hour. IX.	Ratio of Total Weight of Cinders and Sparks to Weight of Coal Fired. X.
1	15	1	1.93	791.5	45.23	21.90	12.30	34.20	.043
2	35	1	2.98	1464.8	83.70	41.20	63.20	104.4	.071
3	35	1	3.02	1513.6	86.50	46.10	49.90	96.00	.063
4	35	1	3.00	1557.1	88.98	45.00	63.40	108.4	.070
5	55	1	3.57	1884.4	107.68	127.5	157.2	284.7	.151
6	35	3	4.88	2017.7	115.29	110.0	67.30	177.3	.088
7	15	9	4.99	2121.0	121.20	215.5	78.00	293.5	.138

It is to be noted from the data given in Table I that the draft conditions for the tests under consideration range from 2 to 5 inches of water; that the coal burned per hour varies from

790 to 2100 pounds, which is equivalent to a rate per hour of from 45 to 121 pounds per foot of grate.

The weight of sparks passing up the stack, and cinders collecting in the front-end per hour, respectively, are given in Columns VII and VIII, while the total weight appears in column IX.

Column X gives the ratio of total weight of sparks and cinders to the total weight of coal. It shows that the losses arising from this cause vary from a little more than 4 per cent to nearly 14 per cent of the weight of coal fired, the loss being greatest when the rate of combustion is highest. The relation between the rate of combustion, weight of cinders caught in front-end, the weight of sparks passing out at the stack, and the total weight of sparks and cinders, is shown graphically by Fig. 7, which is plotted from the data given in Table I. The relation between the weight of sparks passing out at the stack and the weight of cinders retained in the front-end as shown by these tests, is not considered conclusive since it must depend somewhat on the length of the test, that is, upon the frequency with which the front-end is cleaned, but the facts are presented as obtained. It appears, however, that Test No. 1 shows a larger loss by the stack than by the front-end but the value of the whole loss for this test is small. Disregarding this test, it appears in general that the spark-losses as compared with the losses by cinders collecting in the front-end, increase as the rate of combustion increases. Thus in Test No. 2, the stack losses are less than half the total loss; while for Test No. 7 they constitute more than two-thirds the total loss. The results of Tests, Nos. 2, 3, and 4 are of especial interest, since they were run under conditions which gave very nearly identical rates of combustion and served as a check one upon the other. Test No. 5 shows a cinder-loss relatively higher than that of either Tests Nos. 6 or 7. This, while unexpected, may possibly be accounted for by the fact

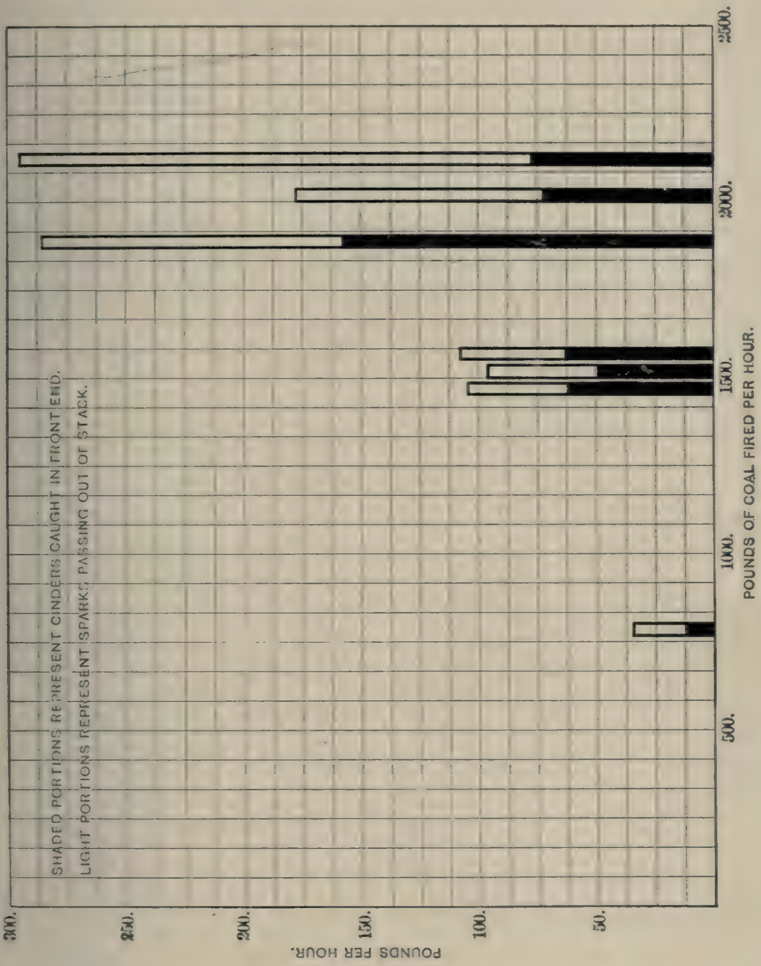

Fig. 7.

that this was a high-speed test. The draft of 3.57 inches resulted from exhaustive pulsations so rapid as to give great steadiness to the outflowing jet of steam.

Test No. 6 should be compared with Test No. 3 rather than with Test No. 5, since Test No. 3 has the same speed; while Test No. 5, as already noted, was run with a much higher speed. The smaller values given for Test No. 6, as compared with those derived from the preceding, if not the result of inaccuracies, must be due to the fact that the cut-off for this test was considerably increased as compared with that of all the preceding tests; the result being that while the draft was stronger and while more coal was burned, it did not have the same effect upon the fire as that produced by the sharper and shorter blast. However, the data is not sufficient to be conclusive upon this point.

Test No. 7 was run under a long cut-off with the throttle partly closed and at a slow speed, the conditions being such as to give a very strong exhaust-action. The draft was greater than for any of the preceding tests and more coal was burned per unit of time. The weight of cinders caught in the front-end is not greatly in excess of the weight of the preceding tests, and is even less than for Test No. 5, but the weight of sparks passing out of the stack is greater than for any other test; the strong blast evidently tending to clear the front-end of a portion of the accumulation which otherwise would have lodged there.

In conclusion, it should be noted that the value of the fuel-loss by sparks and cinders, while depending chiefly upon the rate of combustion, is affected also by the character of the exhaust which in turn is dependent upon the cut-off and speed. As these losses increase, the relative proportion of the whole escaping by the stack increases; a result which may in part be due to the limited capacity of the front-end and to a more perfect scouring action arising from the stronger currents within it.

As already noted, the results thus far discussed were obtained in connection with Brazil block coal, a coal which being light and rather friable, lends itself to the production of a rather high percentage of sparks and cinders. Later investigations made at Purdue in connection with five different samples of bituminous coal submitted by the Big Four Railroad gave results which are of interest in this connection.

The apparatus used and the methods employed were essentially the same as those described in the preceding test.

Values of the spark-losses for each of the several samples of coal tested are presented in Table II.

TABLE II.*

SHOWING WEIGHT OF CINDERS AND SPARKS FROM THE PURDUE LOCOMOTIVE, SCHENECTADY NO. 2, WHEN USING FIVE DIFFERENT GRADES OF COAL.

Number. I.	Designation of Sample of Coal. II.	Speed in Miles per Hour. III.	Position of Reverse Lever. Notches forward of Centre. IV.	Draft in Inches of Water. V.	Total Pounds of Coal Fired per Hour. VI.	Pounds of Coal Fired per Square Foot of Grate-surface per Hour. VII.	Pounds of Water Evaporated per Square Foot of Heating Surface per Hour. VIII.	Pounds of Sparks Passing out of Stack per Hour. IX.	Pounds of Cinders Caught in Front End per Hour. X.	Total Pounds of Cinders and Sparks per Hour. XI.	Ratio of Total Weight of Cinders and Sparks to Weight of Coal Fired XII.
1	E.	15	5	1.51	685	40.30	4.53	14.90	20.97	35.87	.052
2	E.	50	2	5.13	2025	119.1	10.02	294.5	174.0	468.5	.231
3	E.	30	8	5.73	2161	127.1	10.54	311.4	145.8	457.2	.211
4	D.	15	5	1.70	905	53.30	4.72	13.50	31.86	45.36	.050
5	D.	50	2	5.40	2402	141.3	9.82	289.9	124.4	414.3	.172
6	D.	30	8	6.98	2880	169.4	11.11	448.2	128.5	576.7	.200
7	C.	15	5	1.77	983	57.80	4.91	12.50	16.98	29.48	.030
8	C.	50	2	5.34	2403	141.3	9.95	198.7	127.8	326.5	.136
9	C.	30	8	5.74	2606	153.3	10.24	253.4	124.6	378.0	.145
10	A.	15	5	1.70	782	46.00	4.78	16.20	28.40	44.60	.057
11	A.	50	2	5.67	2045	120.3	9.87	208.6	120.0	328.6	.161
12	A.	30	8	6.32	2364	139.1	10.34	208.9	149.6	358.5	.151
13	B.	15	5	1.89	831	48.90	4.76	10.60	24.95	35.55	.040
14	B.	50	2	5.67	2235	132.0	9.90	236.1	126.4	362.5	.162
15	B.	30	8	6.40	2491	146.5	10.70	313.8	133.4	447.2	.180

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* Compiled from a paper on "Tests of Coal for Locomotives," by William Garstang, Supt. of Motive Power C. C. C. & St. L. R. R. Proceedings of Western Railway Club, Dec. 25, 1898.

The results show that when the boiler was worked under conditions which gave an evaporation of about 5 pounds of water per square foot of heating-surface per hour, 5.2 per cent of sample E was lost in the form of sparks and cinders; also, that 5 per cent of sample D was lost from the same cause, and so on. When the rate of evaporation was about 10, the losses by sparks amounted to 22.1 per cent and 18.6 per cent of samples E and D, respectively. It is significant that, with one exception, those samples giving the highest evaporation also gave the largest spark-losses. Two conditions probably account for this fact. First, the purer coals have a lower specific gravity and, hence, respond to the draft-action more easily than coals intermixed with non-combustible matter; secondly, in general, the lighter the ash, the larger the percentage of ash which, instead of falling through the grate, passes out with the sparks and adds its mass to their weight.

TABLE III.

SHOWING CHEMICAL ANALYSIS OF SPARKS FROM THE PURDUE LOCOMOTIVE, SCHENECTADY NO. 1, WHEN USING BRAZIL BLOCK COAL.

Number. I.	Total Pounds of Dry Coal Fired per Hour. II.	Pounds of Dry Coal per Square Foot of Grate-surface per Hour. III.	Pounds of Sparks Passing out of Stack per Hour. IV.	Composition of Sparks.*				Pounds of Dry Coal Equivalent to Spark-losses per Hour. IX.	Pounds of Dry Coal Equivalent in Heating Value to One Pound of Sparks X.	Value of Spark-losses in Per Cent of Dry Coal Fired. XI.
				Per Cent of Fixed Carbon. V.	Per Cent of Volatile Matter. VI.	Per Cent of Combined Moisture. VII.	Per Cent of Ash. VIII.			
1	1,074	61	61.5	61.74	4.36	1.82	32.08	46	.75	4.3
2	1,078	84	95.1	64.88	4.16	1.82	29.14	77	.81	7.2
3	1,086	124	128.6	71.32	3.45	1.66	23.57	111	.86	10.2
4	1,038	241	176.3	76.44	3.29	1.86	18.41	161	.91	15.5

* All chemical analyses were made by Charles D. Test, A.C., under the direction of Dr. W. E. Stone.

13. Heating Value and Coal Equivalent of Sparks.—An analysis of sample sparks obtained under different rates of combustion when using Brazil block coal is presented in Table III.

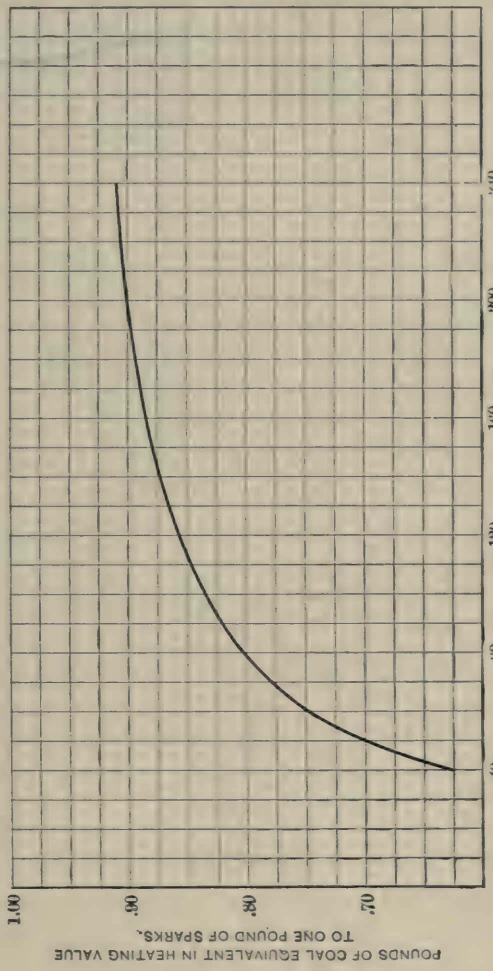

FIG. 8.

Among the significant facts disclosed by this table is that relating to the varying fuel-value of the sparks. Thus the sparks which result from a rate of combustion of 61 pounds of coal per square foot of grate per hour are composed of one-third ash, while those which were obtained under a rate of combustion of 241 pounds have less than one-fifth their bulk composed of ash; in other words, as the weight of sparks increases, their fuel-value increases.

From the facts given in Table III, the relationship between the rate of combustion and the fuel-value of sparks resulting may be established. Such a relationship is shown by Fig. 8, which shows the fraction of a pound of coal that is the equivalent of a pound of sparks, which may result from different rates of combustion. By use of this curve an estimate of the value of the spark- and cinder-losses for the seven tests pre-

TABLE IV.

SHOWING HEATING VALUE OF SPARKS FROM THE PURDUE LOCOMOTIVE, SCHENECTADY NO. 1, WHILE USING BRAZIL BLOCK COAL.

Number of Test. I.	Speed in Miles per Hour. II.	Position of Reverse-lever. Notches forward of Centre. III.	Draft in Inches of Water. IV.	Total Pounds of Coal Fired per Hour. V.	Pounds of Coal Fired per Square Foot of Grate-surface per Hour. VI.	Total Pounds of Sparks per Hour. VII.	Pounds of Coal Equivalent in Heating Value to One Pound of Sparks. VIII.	Pounds of Coal Equivalent in Heating Value to Sparks for Test per Hour. IX.	Per Cent of Fuel Accounted for as Sparks. X.
1	15	1	1.93	791.5	45.23	34.20	.665	22.7	2.9
2	35	1	2.98	1464.8	83.70	104.4	.801	83.6	5.7
3	35	1	3.02	1513.6	86.50	96.00	.807	77.5	5.1
4	35	1	3.00	1557.1	88.98	108.4	.812	88.0	5.7
5	55	1	3.57	1884.4	107.68	284.7	.841	239.4	12.7
6	35	3	4.88	2017.7	115.29	177.3	.851	150.9	7.5
7	15	9	4.99	2121.0	121.20	293.5	.856	251.2	11.9

viously under consideration may be had. Such an estimate in terms of equivalent weight of coal is shown in Table IV.

The values given in Column VIII of this table (Table IV) were taken directly from the curve in Fig. 8. Those in Column IX were obtained by multiplying the values in Columns VII and VIII. The values in Column X were obtained by dividing 100 times the values in Column IX by the values in Column V.

It will be seen that the spark- and cinder-losses, measured in terms of the equivalent weight of coal are, for the test for which the power was lightest, equivalent to 22.7 pounds per hour and for the test for which the power was highest, 251.2 pounds per hour; these values being equivalent to 2.9 per cent and 11.9 per cent of the weight of coal fired respectively.

Too much emphasis cannot be given the fact that these results were derived while the engine was working under conditions that are in no wise exceptional and the fact that they show that more than 13 per cent of the fuel which passes the furnace-door may completely pass the heating-surface of the boiler unconsumed, is one which should merit attention.

It has already been shown that the size of the sparks varies with the extent of the spark-losses. It should now be evident that under low rates of combustion, the solid matter discharged from the top of the stack consists of a very fine, almost sooty deposit, having a very low fuel-value, while as the volume of sparks is increased, the size of individual particles becomes greater and their fuel-value is also increased.

14. Conclusions as to Cinder- and Spark-losses.—The results of the investigations herein referred to and in part described, justify the following general conclusions:

1. Sparks are composed of partially consumed coal and ash.

2. The total weight of cinders and sparks passing the heat-

ing-surface of the boiler of a locomotive increases as the rate of combustion is increased, and under conditions approaching maximum production may, in connection with narrow fireboxes, equal 20 per cent of the weight of coal fired.

3. Other things being equal, it is likely that the condition of the fire and the character of the exhaust have considerable influence upon the weight of cinders produced.

4. The fuel-value of a unit weight of sparks or of cinders increases as the volume discharged increases.

5. The relation between the weight of cinders deposited in a long front-end and the weight of sparks discharged from the top of the stack is not clearly defined by the experiments, since in general it must be a function of the length of the test and of the carrying capacity of the front-end, but under high rates of combustion it appears that the weight discharged from the top of the stack is in excess of that from the front-end.

6. The size of sparks varies with the amount produced. Thus, when conditions are such as result in small spark-losses, the sparks themselves are insignificant in size, while the reverse conditions result in increased size of sparks.

7. A coal burning to light ash gives a higher spark-loss than one burning to clinker.

CHAPTER IV.

SPARK-PREVENTION—FRONT-END ARRANGEMENTS

15. **Spark-prevention.**—The problem of spark-prevention is beset with difficulties. To secure the high rates of combustion which are necessary in locomotive service, there must be a free passage for air and for the products of combustion from the grate to the top of the stack. Anything which may be interposed in the currents of gases moving along this course affects the draft and generally interferes with its action. To employ obstructions which will serve in suppressing all escape of sparks from the stack would choke the draft and make the locomotive inoperative. In the practical working out of the whole problem, therefore, spark-prevention is considered as constituting but one of several factors, freedom of draft and its uniform action over the whole area of the grate constituting other and equally important factors. Thus it is that so-called spark-arresters are inseparably connected with draft appliances and that both together go to make up the front-end arrangement. Again, the construction of the furnace may affect the volume of sparks produced, the presence of a brick arch usually operating to reduce spark production.

16. **Increased Grate-area.**—Where a given quantity of fuel is to be burned, the effect of increasing the grate-area is to lower the rate of combustion per foot of grate-surface. This means that the volume of air which, in passing a smaller grate, would flow in strong currents, will, when distributed

over the area of a larger grate, flow much less rapidly. Hence, it may be said that increasing the grate-area diminishes the intensity of the draft-action upon the fire. With a less energetic draft-action, the production of sparks is necessarily reduced. Obviously, the grate cannot be regarded as a spark-arrester, but since the grate is the source from which sparks arise, and since when other things remain the same, an increase in its area diminishes the volume of sparks produced, its proportions are not to be omitted in a consideration of the general subject of spark-prevention.

17. The Brick Arch.—The form of the brick arch and its location within the fire-box is well shown by Fig. 9 which is a vertical section of the furnace end of a locomotive boiler. In the case illustrated the arch is supported upon studs or brackets in the side-sheets of the furnace and extends from the front-sheet obliquely backward. By its presence the length of flame-way is increased and particles of fuel leaving the grate are thereby held in suspension for a longer time before entering the tubes, the result being that particles which would otherwise be sparks or cinders are in many cases completely burned to ash. The arch, also, serves to distribute the draft over the grate and in so doing it doubtless contributes to the efficiency of the furnace-action.

From the furnace the sparks pass directly to the front-end, and it is here that provision for receiving them is chiefly provided.

18. A Typical Front-end arrangement, as used on Schenectady No. 2, the experimental locomotive at Purdue University, is shown in Fig. 10.

The exhaust-steam from the cylinders passes through the exhaust-ports into the exhaust-pipe, *E*. From *E* it passes through the exhaust-tip, *t*, and is directed upwards through the petticoat-pipes, *P*, and out by the stack, *S*. This action produces a partial vacuum in the smoke-box, in response to which a current of hot gases is induced in the tubes *T*. The hot gases finding their exit from the tubes are at once intercepted by the diaphragm, or baffle-plate, *D*, by which they are deflected downwards, as shown by the arrows. The diaphragm begins above the top row of tubes and extends obliquely downwards terminating in a variable slide, *V*, which may be raised or lowered through a considerable range to meet the varying conditions of service.

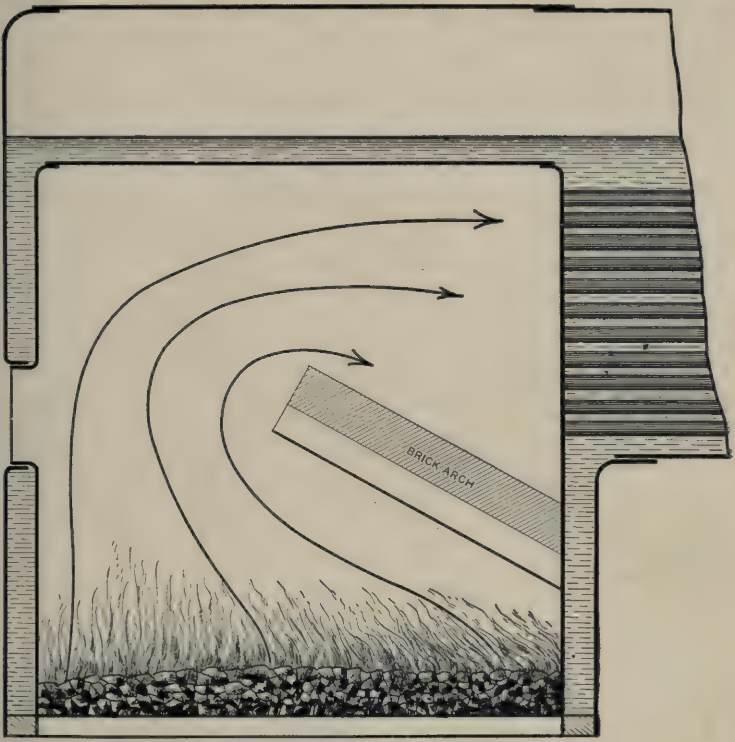

FIG. 9.

Beyond the diaphragm is the netting, *N*, which divides the smoke-box into a lower and an upper chamber. The door, *C*, is interposed in the netting to give access to the upper chamber. Above the netting are, or may be, petticoat-pipes, *P*, though in many locomotives they are entirely omitted. Above the petticoat-pipes is the stack, *S*. At *H* is a cylindrical extension (not shown) which is known as the cinder-pocket,

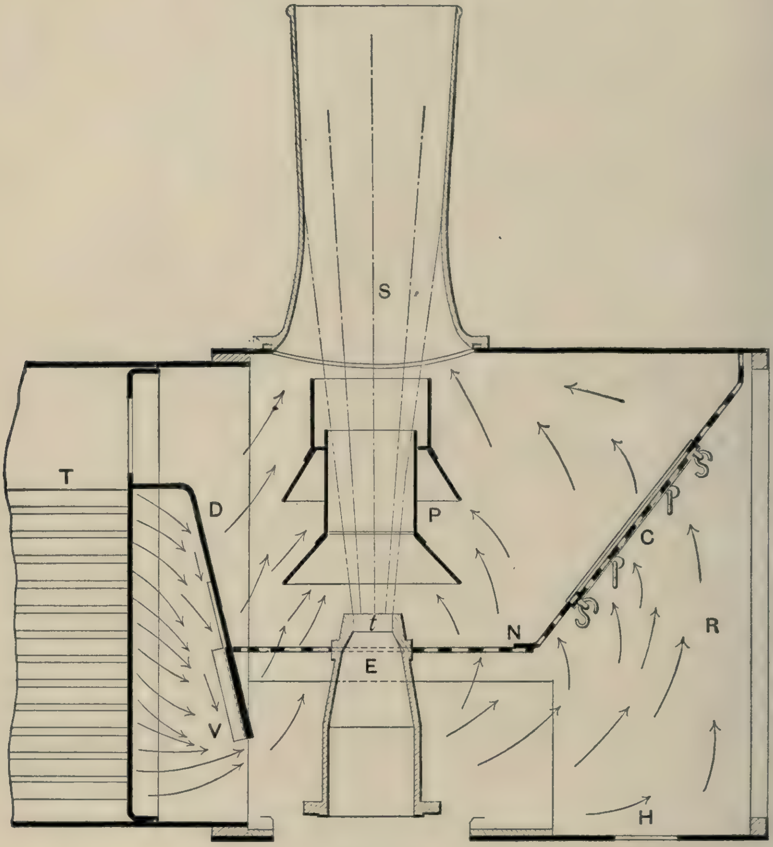

FIG. 10.

through which the cinders collecting in the front-end may be removed. The course, therefore, of the gases passing under the diaphragm is through the netting, in and around the petticoat-pipes, where they mingle with the jet of exhaust-steam and thence out through the stack. It will be seen that a spark which is to pass out at the top of the stack is first met as it emerges from the tubes by the diaphragm against which it impinges. From the diaphragm it is deflected downward, and after passing the narrow opening below the diaphragm it rises to the netting. If it is very small it may at once pass the netting. If it is large it will be churned about in the front-end and hammered against the netting until it is sufficiently pulverized to go through. It is by this process that particles which otherwise would be discharged as live sparks have all the fire hammered out of them before they reach the top of the stack. A detailed description of the several elements entering into the construction of the front-end is as follows:

19. Diaphragm or Baffle-plate. — The function of the diaphragm is twofold. First, it acts as a deflector to throw the solid particles away from the point of strongest exhaust-action, and to break up large particles which impinge against it. Secondly, it acts as draft-regulating device. If the diaphragm were absent, the upper rows of tubes, owing to their proximity to the exhaust-jet, would be affected by the exhaust-action more than the lower tubes. The diaphragm acts as a shield to the upper tubes, checking the draft action in them and, by so doing, augmenting the current in the lower tubes. If the draft is not well distributed in the tubes, the fuel burns unevenly and the steaming-action of the boiler is impaired. Mr. C. H. Quereau * gives the following as present American practice (1900) in the design and arrangement of the diaphragm:

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* Report to International Railway Congress, Paris, 1900.

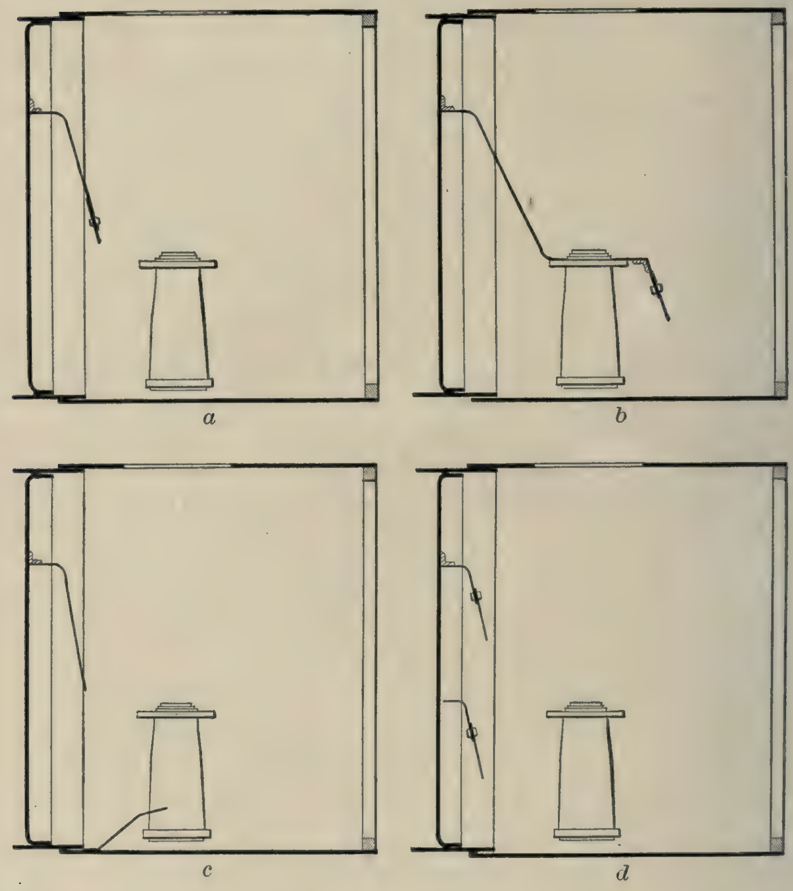


FIG. 11.

"Fig. 11 shows the types of diaphragms generally used. Arrangement *a*, with the plates back of the exhaust-pipe, is standard with eighteen roads; arrangement *b*, with the plates extended forward of the exhaust-pipe, is standard with nine roads. Arrangement *b* sweeps the cinders from the front-end so that it is not necessary to clean them either on the road or at terminals, and the cinder-hopper, with the chances of its leaking, are done away with. Two roads use the arrangement shown in *c*. What its special advantage is does not appear. Another arrangement of two plates is illustrated by *d*, which is used by two roads on boilers which are larger than 62 inches in diameter at the forward ring. With boilers of this size it is frequently difficult to distribute the draft uniformly over the fire and at the same time properly clean the cinders from the front-end. Design *d* does this admirably."

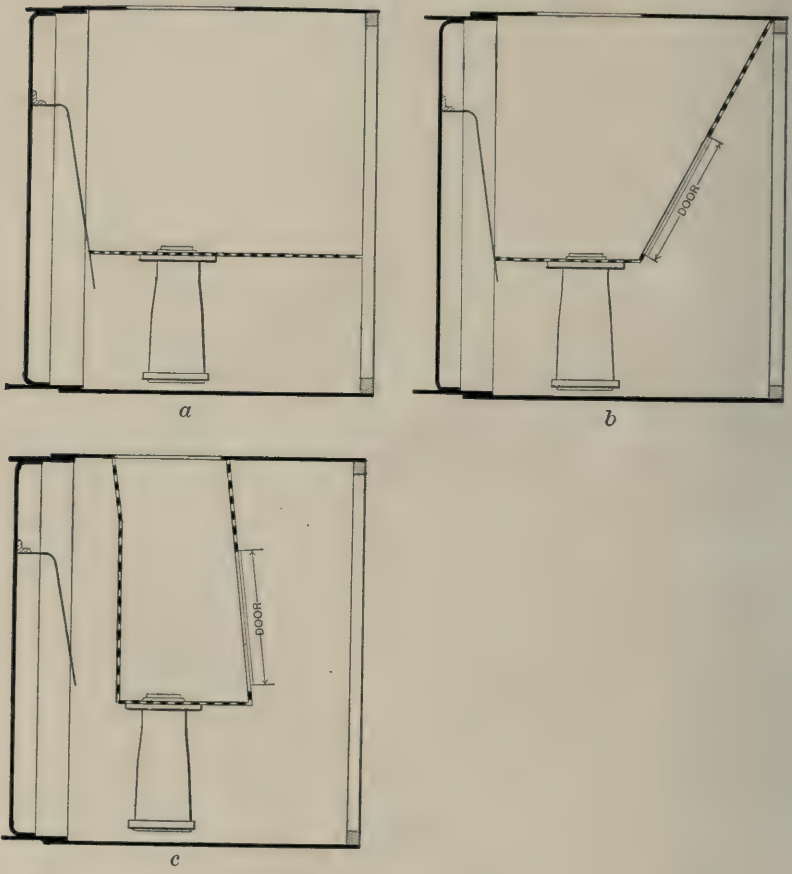
"There has been little change in the general design of the diaphragm since 1890. Three roads have moved their plates from in front of the exhaust-pipe to back of it, and three have reversed this. One road writes as follows: 'The only change we have made since 1890 has been to put the diaphragm back of the exhaust-pipe and steam-pipes to overcome the excessive wear of these pipes. We also find the change has promoted combustion.' "

"It is the almost universal custom to use an adjustable plate on the fixed plate with which to change the distance from the bottom edge of the diaphragm to the bottom of the front-end and in this way distribute the draft evenly over the flues and grate."

20. **Netting.**—The purpose of the netting is to prevent particles of fuel from passing out of the stack in a state of ignition. It must be sufficiently open to permit the furnace-gases to pass freely through and to minimize the danger of its filling up with smoky deposits. It must be sufficiently close to prevent escape from the stack of such larger particles as are likely to be in a state of ignition.

Thus, Mr. Quereau* reports as follows:

"Present practice, in so far as the general arrangement of the netting is concerned, is shown in Fig. 12, from which it



a

b

c

Fig. 12.

appears that four roads use arrangement *a* and twenty-three roads *b*. The controlling reason for the design *b* seems to be convenience in getting at the exhaust-tip and baffle-plates, and an increased area of netting. Diagram *c*, commonly called the basket-netting, is used to some extent. This is the most convenient form, in so far as ease in getting at the deflector-plates and steam-pipe joints is concerned, and equally as convenient as form *b* when it is necessary to reach the tip, but, in front-ends of large diameters, form *c* is liable to cause an accumulation of cinders in the front-end, probably because the currents around each side meet in front, causing an eddy, and because the currents do not strike the netting at right angles, increasing the resistance."

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* International Railway Congress, Paris, 1900.

"The preference of the roads as to the material used in the netting is shown by the fact that twenty use woven wire and seven, perforated plates. The favorite dimensions for wire-netting is that with 2½ × 2½ meshes per square inch, with the wires, .12 inch in diameter, used by nine roads. Next comes a netting with the same mesh, but the wire .109 inch in diameter, used by five roads. Netting with meshes as fine as 8 × 8 per square inch and wire .049 inch in diameter is used by one road which runs through a country specially liable to fires."

.28X.

"In the perforated plates the openings are usually about 1½ × $\frac{3}{16}$ inch or ¼ inch with the corners filletted, with a ⅛-inch bridge between, the sheet through which the holes are punched being usually ⅛ inch thick, as shown in Fig. 13."

21. **Petticoat-pipe** can only be used with advantage when the exhaust-nozzle is set low. In such cases it helps to distribute the action of the exhaust, generally permitting the deflector-plate to come higher than otherwise. The result is a more open, or less obstructed front-end. The petticoat-pipe provides additional channels through which the gases of the smoke-box are fed to the jet of steam and by so doing they serve to transform the comparatively small and powerful jet of

steam into a larger but less intense stream of mixed gases and steam. This issuing from the first petticoat-pipe becomes the moving force to act upon other portions of gas; the moving stream augmented in size by fresh additions enters the second petticoat-pipe from which it issues to again repeat the process before entering the base of the stack. The petticoat-pipes serve to distribute the load of smoke-box gases taken up by the steam-jet, and by defining the boundaries of the combined jet, they prevent its losing energy by breaking up into eddies. In so far as they accomplish this they contribute to the efficiency of the exhaust-action.

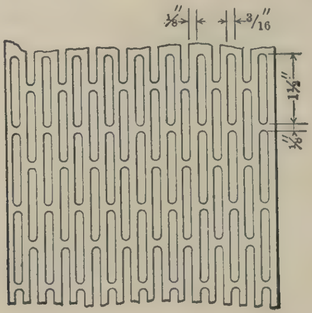

FIG. 13.

As a practical matter it should be said that experience proves that the adjustment of the petticoat-pipes to a proper height relative to the other elements affecting the draft is a very important matter. A few inches higher or lower may have a decided effect on the steaming qualities of the boiler. In many cases petticoat-pipes are entirely omitted and when used they may be double as shown by Fig. 10, or single.

22. Exhaust-pipe.—There are two forms of exhaust-pipes in general use, the single and the double. In the single exhaust-pipe the steam from both cylinders escapes through the same tip as shown by Fig. 14. The double exhaust-pipe allows the steam from each cylinder to exhaust through an independent tip as shown by Fig. 15.

The object of any design or arrangement of exhaust-pipe is to serve in carrying off the exhaust-steam from the cylinders with the least amount of back pressure and at the same time give a jet having sufficient energy to produce the required draft. A double nozzle provides a separate exit for the steam from each cylinder; a single nozzle requires the steam from both cylinders to emerge from the same opening. With the single nozzle, however, the passages are kept separated until

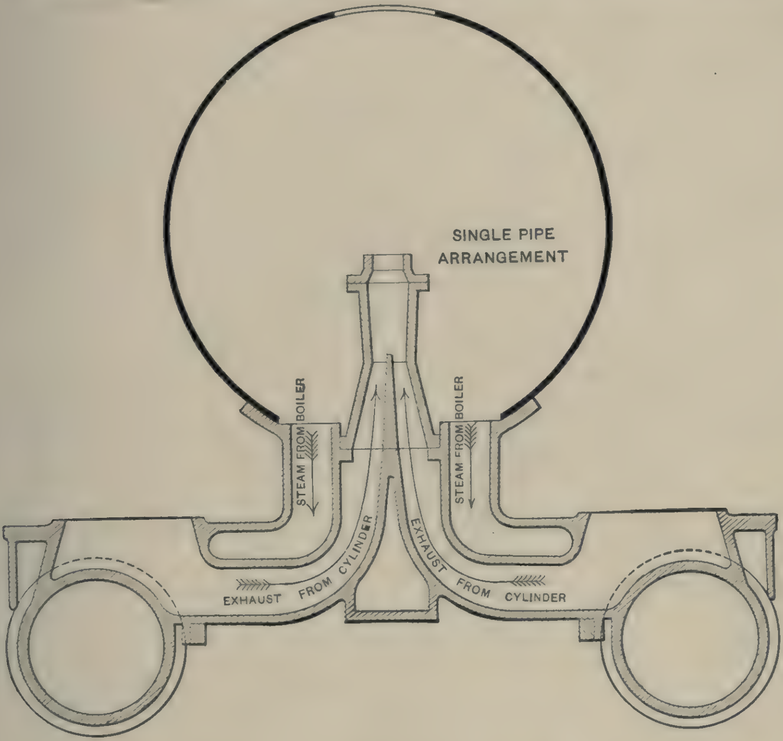

Fig. 14.

the point of discharge is nearly reached. When the exhaust-pipe is very short or when other details of the whole arrangement of ports and pipes are such that a single nozzle might allow steam exhausted from one cylinder to pass into the exhaust-passage of the other cylinder, a double exhaust-pipe must be used. Under conditions such as are shown by Figs. 14 and 15, it is perhaps sufficient to say that good practice involves both forms and that both forms have their advocates. The Master Mechanics' Committee, however, recommends the

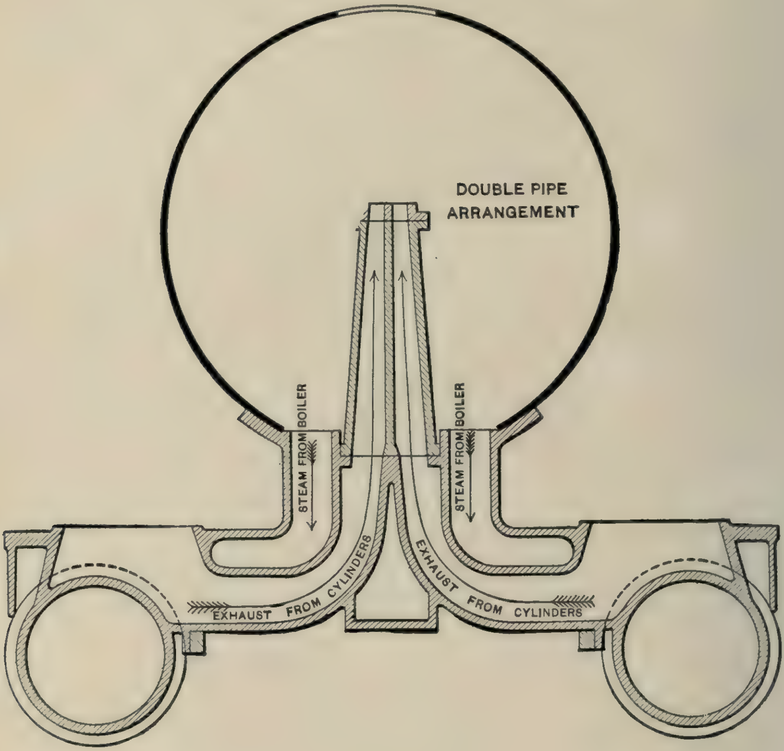

Fig. 15.

single pipe (Fig. 14) as the more efficient of the two arrangements.

23. Exhaust-tip.—The exhaust-tip is the fixture at the end of the exhaust-pipe. It is the tip which governs the size, shape, and velocity of the exhaust-jet. Exhaust-tips may, in general, be either fixed or variable. Fixed tips are designed to meet the average conditions of service and are of various forms as shown by Fig. 16.

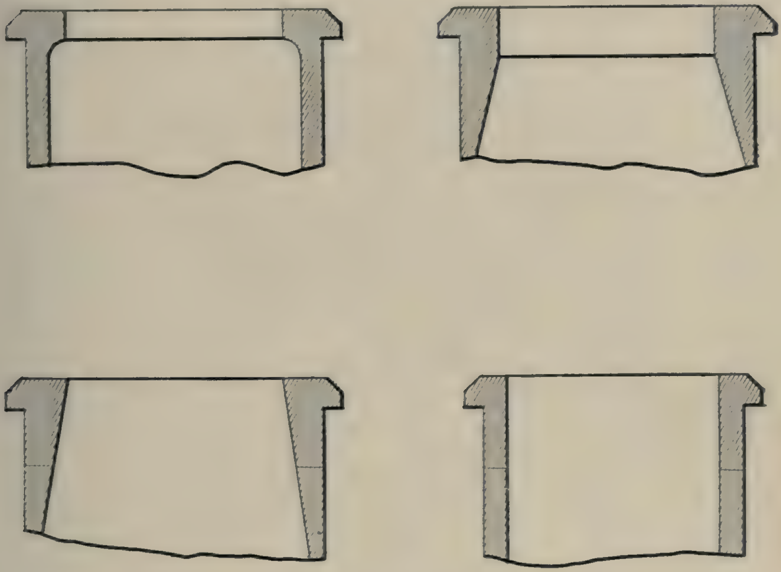

FIG. 16.

The variable exhaust-tips are so designed that the area of the opening may be changed at the will of the engineer as the conditions of service may require, or controlled by the position of the reverse lever or through the action of some other part of the mechanism of the engine. In theory the variable exhaust-tip is correct, but the difficulties to be overcome in its design and operation have thus far prevented it from coming into general use in this country. For a discussion of the relative merits of fixed and variable exhaust-tips as used on foreign locomotives, the reader is referred to a report by Mr. Eduoard Sauvage to the International Railway Congress, Paris, 1900.*

24. **Smoke-stack.**—The smoke-stack serves to convey the gases and the exhaust-steam from the smoke-box to the outer air. There are two general classes, the open stack and the diamond stack. Open stacks may be straight or tapered. Until quite recently they have ordinarily been straight as shown by Fig. 33, but they are now generally tapered as shown by Fig. 10 and by Figs. 23 to 29. The opinion is prevalent that the double-tapered stack (Fig. 10) is more efficient than the straight stack and it is known to be less subject to wear from the action of sparks.

The open stack is used in connection with the extension front; the diamond-stack, in connection with the short front-end. Fig. 10 is a type of the former, and Fig. 17 of the latter. The diamond-stack is essentially a combination of stack and spark-arrester. The solid particles of fuel impinge against the cone at the top of the stack and are deflected into the bonnet. If small, they may be swept out through the netting at the top, but if large they are retained in the bonnet where, by the repeated action of the exhaust, they are hammered about until broken sufficiently to pass through the netting.

The diamond-stack is the older type of construction, and while still somewhat used it is nevertheless gradually disappearing from service.

25. **Extended Front-end.**—The extended front-end is a necessary part of the general arrangement, the details of which constitute the subject of the several paragraphs immediately

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* Railroad Gazette, pp. 448–450, June 29, 1900.

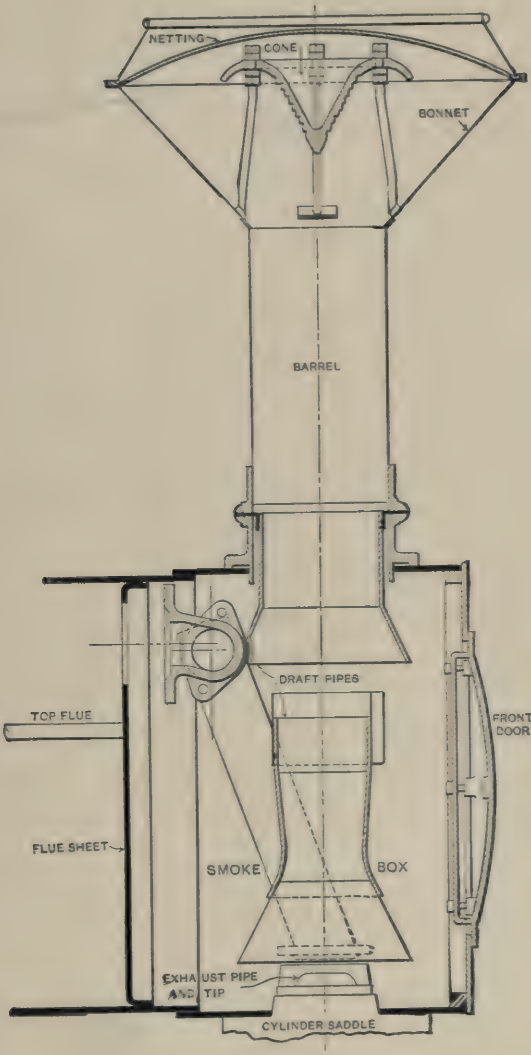

NETTING
CONE
BONNET
BARREL
DRAFT PIPES
TOP FLUE
FRONT DOOR
FLUE SHEET
SMOKE
BOX
EXHAUST PIPE AND TIP
CYLINDER SADDLE

FIG. 17.

preceding, but its dimensions may be varied within rather wide limits. Originally it was intended to be large in order that it might supply sufficient space in which cinders could be entrapped. This is shown by the following statement of the inventor, as quoted by Mr. Bell:*

"The nature of my invention consists in extending the smoke-arch or smoke-box (front-end) so far beyond the chimney (stack) and the blast-pipe that the sparks and cinders ejected from the stack of pipes (tubes) connecting the smoke-arch (front-end) with the furnace may be thrown so far forward beyond the draft or current of smoke passing from the stack (the tubes) to the chimney (stack) as to fall down and settle or be retained within the smoke-box. . . . I have found that by extending the smoke-box (front-end) some considerable distance, that is, about 18 inches or more, in manner as described and represented, beyond the course of the draft, most, if not all of the sparks and cinders, will pass beyond the current of smoke and be deposited in the smoke-box (front-end)."

In practice it is found that while the front-end will retain some sparks, it cannot hold all which would naturally accumulate except for a brief interval. This being true the difficulties of freeing the front-end of its accumulation, between terminals, has led to the general adoption of such proportions as will give best results in the matter of draft, regardless of its capacity for cinders. Data already quoted (Table III, Chapter III) show that with a front-end so designed as to be capable of holding large amounts of sparks, the volume passing out of the stack is greater than that which is entrapped. In general, therefore, it may be said that the front-end of to-day serves the purpose of providing room for a liberal area of netting. It is not regarded as of value as a means for retaining cinders.

---

* J. Snowden Bell before the Western Railway Club, September, 1899.

26. Practice in Front-end Arrangements.—Thus far we have considered the various details which have to do with the maintenance of draft and the prevention of sparks. We may now take a more general survey to ascertain what are the differences which characterize present-day practice, and in so doing will again have resort to the excellent paper of Mr. Bell from which the following is largely abstracted and arranged.

Referring first to the diamond stack, attention is called to Fig. 17, which represents the standard of the Union Pacific Railway for the past fifty years, and to Figs. 18 and 19, which show the adaptation of this practice to some large consolidation engines recently built for the same road. It will be seen that the smoke-box is unobstructed by either diaphragm or netting, that the nozzles are low and that they have a long petticoat-pipe above them. The spark-arresting is accomplished in the stack which is enormously enlarged to accomodate a sufficient area of netting and which carries an inverted "cone" to baffle the sparks. Figs. 20 and 21 represent the standard stack and front-end for burning wood, of the Mexican Central Railroad, which differs from those already described only in minor details and in the proportion of parts.

Returning now to the open stack and the extended front so common in present-day practice, attention should first be given the particular arrangement recommended by the Master Mechanics' Committee on Exhaust-pipes and Steam-passages, of 1896. The Committee made elaborate experiments and established dimensions for exhaust-pipe, tip, petticoat-pipes, and stack which are believed to give maximum efficiency. These are shown by Fig. 22.

While the committee recommended that the smoke-box be made sufficiently long to permit a cinder-pocket or cinder-pot for the discharge of cinders, to be located in front of the cylin-

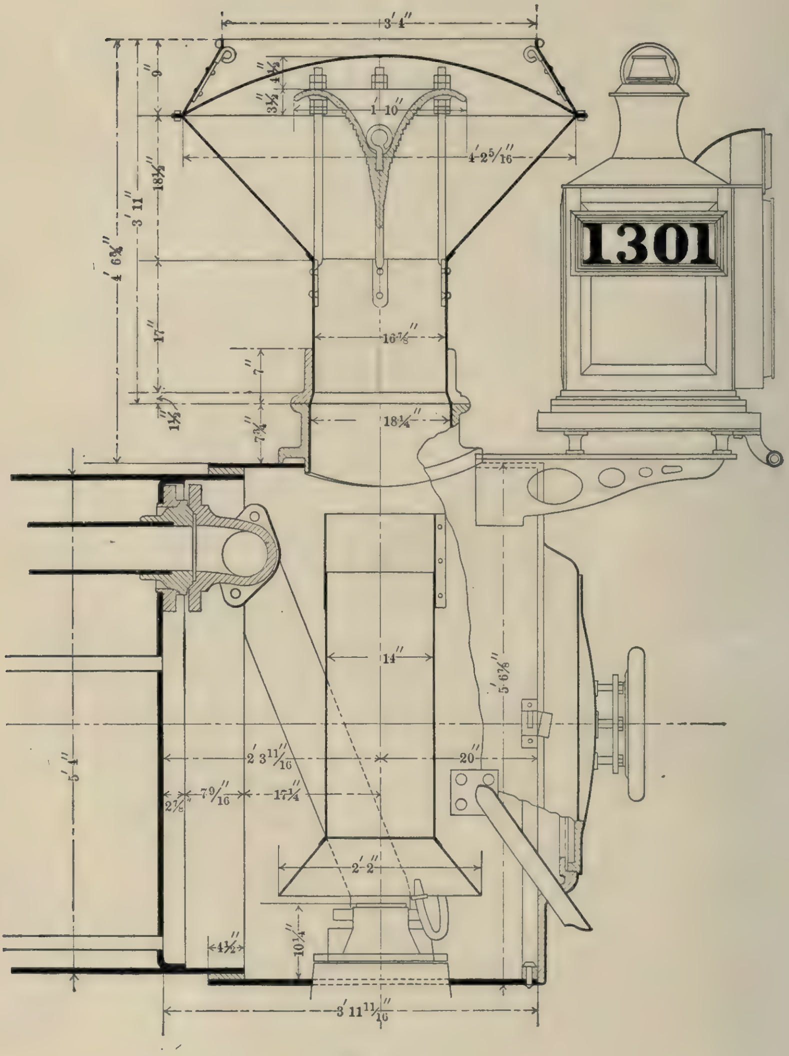

3′ 4″
9″
4½″
3½″
1′ 10″
4′ 2 5/16″
18½″
3′ 11″
4′ 6⅜″
17″
16⅞″
7″
1½″
7¾″
18¼″
1301
14″
5′ 6⅞″
2′ 3 11/16″
20″
5′ 1″
2⅛″
7 9/16″
17¼″
2′ 2″
10¼″
4½″
3′ 11 11/16″

FIG. 18.

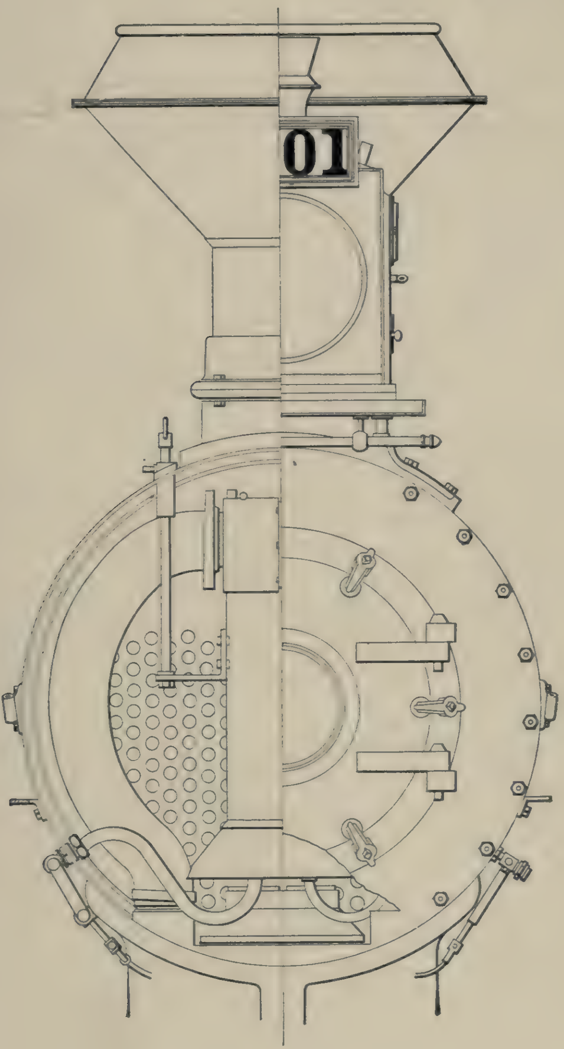
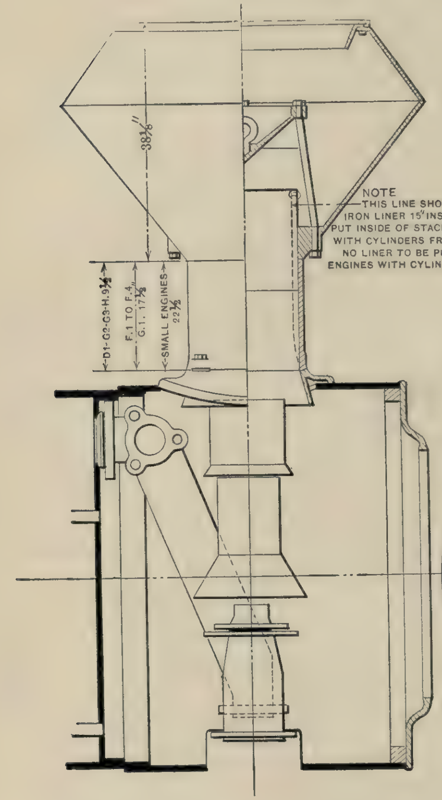


Fig. 19.

der-saddle, as shown in Fig. 25, the fact was generally recognized that the smoke-box, whether long or short, could not, and did not in practice, perform to any extent the function of a cinder receptacle or retainer.



NOTE
THIS LINE SHOWS ⅛" SHEET IRON LINER 15" INSIDE DIAM. TO BE PUT INSIDE OF STACKS ON ALL ENGINES WITH CYLINDERS FROM 15" TO 18" DIAM. NO LINER TO BE PUT IN STACKS ON ENGINES WITH CYLINDERS FROM 19" TO 21"

FIG. 20.

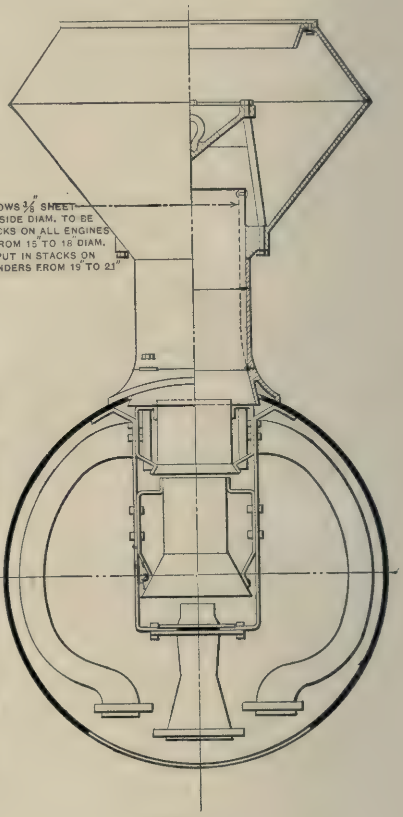


FIG. 21.

In further discussion of the general subject, the Convention agreed that it is possible to so arrange the front-ends of locomotives that they will clear themselves of cinders without throwing live sparks. (Topic No. 2, pp. 103–108, Proceedings of 1898.)

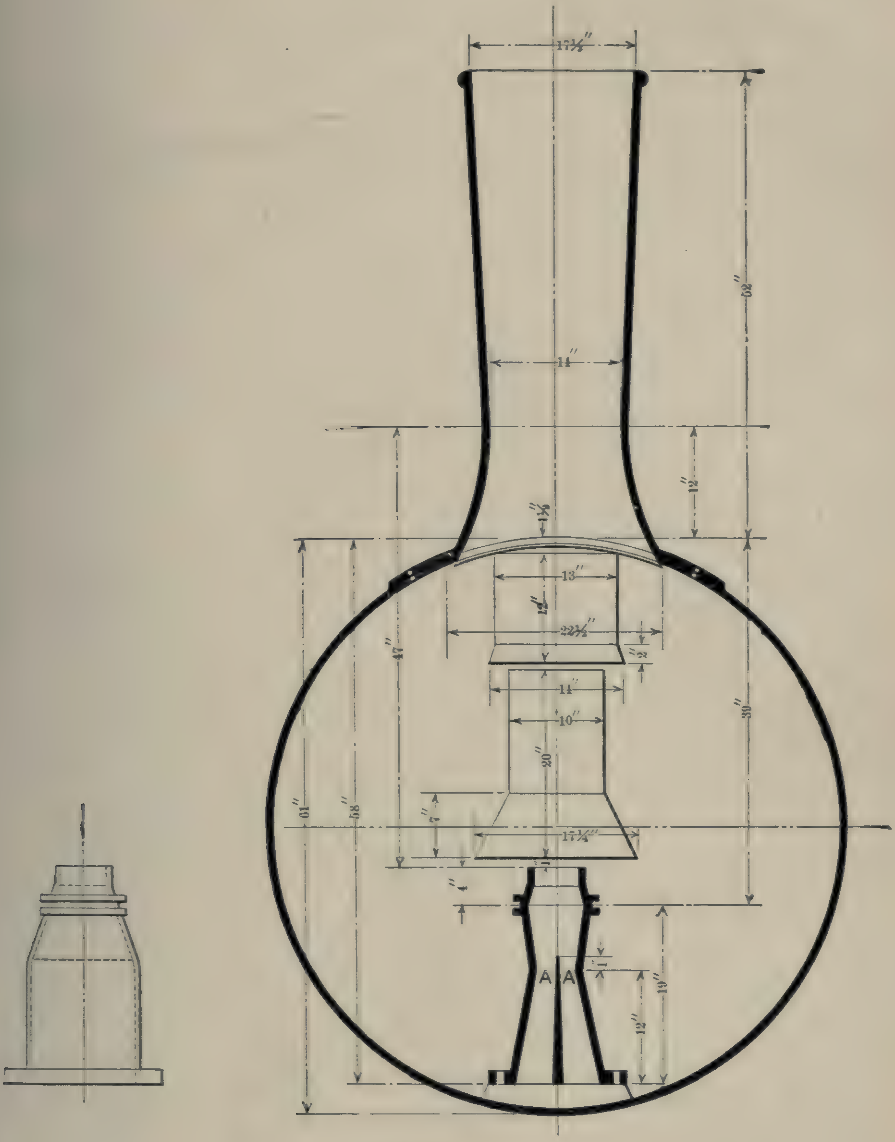


FIG. 22.

The length of the front-end was not definitely fixed by the committee, though the opinion was expressed that a more efficient arrangement would result if it were made shorter than was then (1896) common practice. As a result of this recommendation and of the experience of master mechanics acting individually, we now find many so-called "short" front-ends, though many of the long or "extended" type still remain.

The general design of the Master Mechanics' Committee, as applied to an extended front-end is shown by Fig. 23. The extension of the deflecting-plate in front of the exhaust-pipe is for the purpose of clearing the front-end of cinders. Where this arrangement is employed, the cinder-pot is dispensed with. Fig. 24 shows a self-cleaning front as used on Class U engines of the Norfolk & Western Railway. Mr. W. H. Lewis, Superintendent of Motive Power of that road, in writing to Mr. Bell, with reference to his design, well states the considerations which have led to the adoption of self-cleaning front-ends. He writes as follows:

"The self-cleaning features of these are practically the same, and we have found that it is possible to do away entirely with the cinder-hopper and blower, and experience no trouble with the front filling with cinders."

"I beg to remind you, however, that the general rules to be observed in the arrangement of these spark-arresting devices are largely dependent upon the character of the coal and the service performed by locomotives, and the position of the deflector and diaphragm-plates can only be determined by a careful service test. The satisfactory results which we are now obtaining have thoroughly convinced us that it is not necessary to maintain a long-extended front as a receptacle for cinders, and that only sufficient extension is required to insure the proper area of opening in the perforated plates or

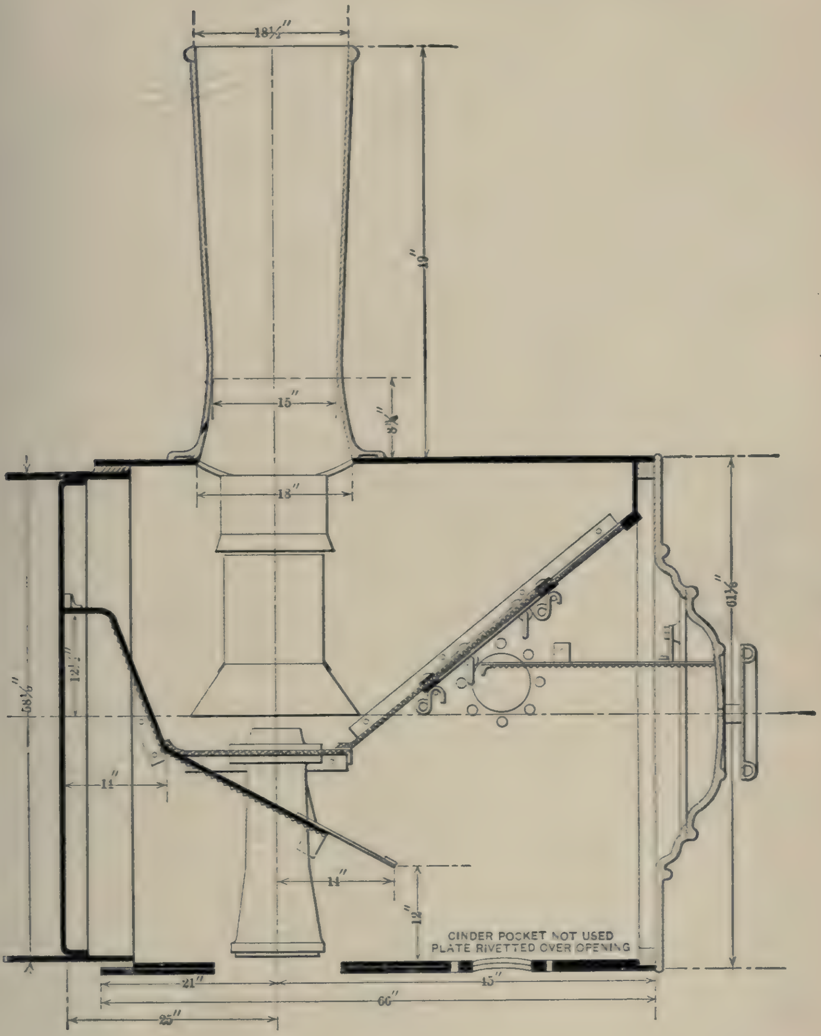

18½"
40"
15"
8⅞"
13"
12½"
68½"
11"
61⅛"
14"
12"
CINDER POCKET NOT USED
PLATE RIVETTED OVER OPENING
21"
45"
60"
25"

FIG. 23.

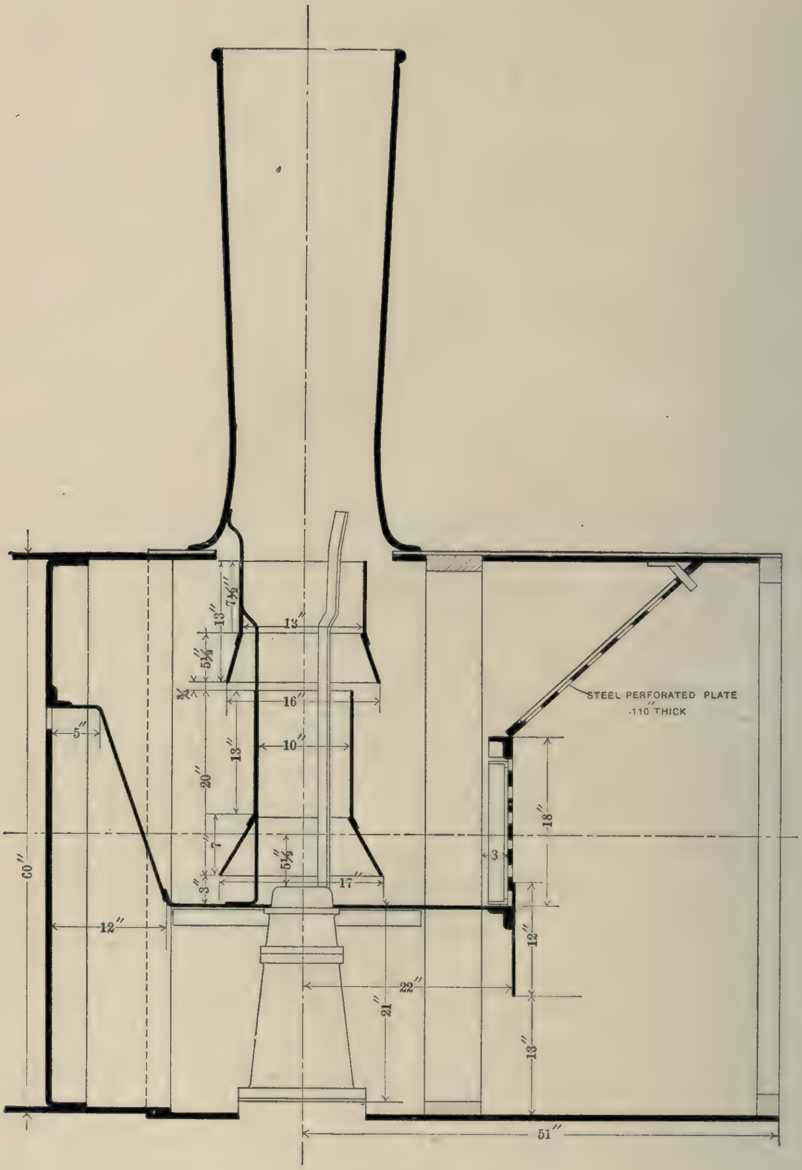

13"
7½"
13"
5½"
¾"
16"
5"
10"
13"
20"
7"
5½"
3"
17"
60"
12"
22"
21"
STEEL PERFORATED PLATE
.110" THICK
18"
3
12"
13"
51"

FIG. 24.

netting used to insure a free draft; in fact, in the number of observations which we made prior to the adoption of the device, it was found that our long-extended fronts accumulated the maximum amount of cinders in a distance of ten miles, in heavy mountain service, so that all of the cinders and sparks which entered the front-end after that time were necessarily thrown out. We, therefore, felt that little advantage might be expected from simply storing the cinders that would accumulate in going a distance of ten miles and running a further distance of fifty or sixty miles without any further accumulation, and that it was thoroughly logical to adopt a device which would relieve the front of cinders entirely."

A front-end which in its length very nearly conforms to the recommendation of the Master Mechanics' Committee is shown by Fig. 25. This is from the drawings of certain classes of small engines on the C. B. & Q. Railway. The general arrangement disclosed by the figure may be accepted as common to very many locomotives in the United States. An arrangement not uncommon is shown by Fig. 26, the illustration being taken from a heavy Atlantic type engine of the C. B. & Q. In this case the exhaust-nozzle is low and the general plane of the netting high, the distance between being spanned by a "basket" form of netting. The diaphragm is almost entirely absent in this design, the whole front being quite free of obstruction. Another arrangement, somewhat similar in principle but involving a lower deflector-plate and petticoat-pipes is shown by Fig. 27.

A front-end employed on ten large engines of the Mexican Central is shown by Figs. 28 and 29. It will be seen that it is very short, that an extension of the deflector is brought to a point forward of the nozzle, and that the netting does not

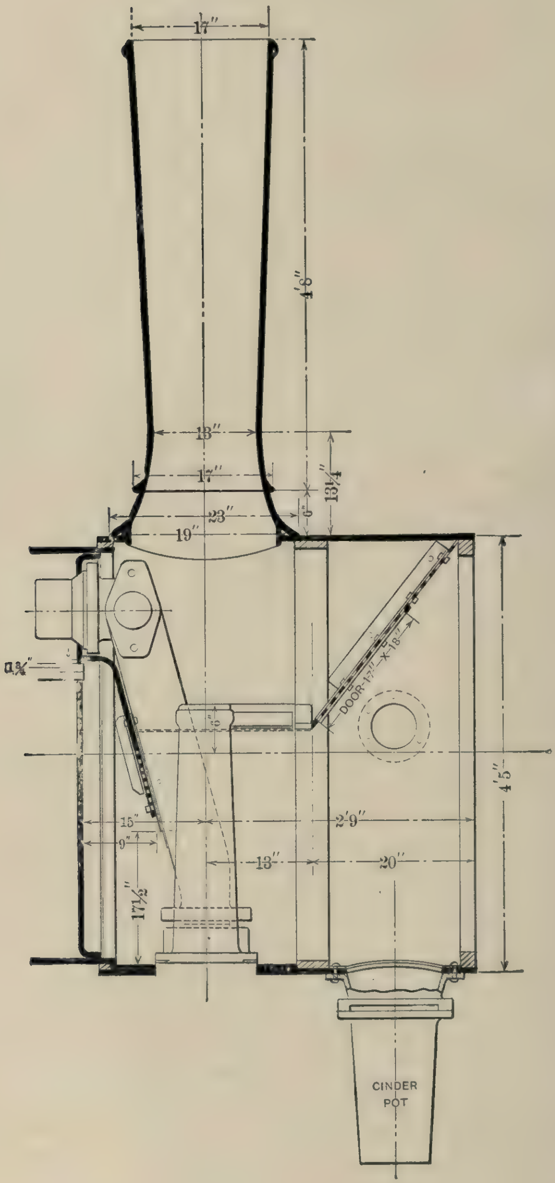

17"
4'8"
13"
17"
13¼"
6"
23"
19"
1⅜"
5"
DOOR-17" X 18"
4'5"
15"
2'9"
9"
13"
20"
17½"
CINDER POT

FIG. 25.

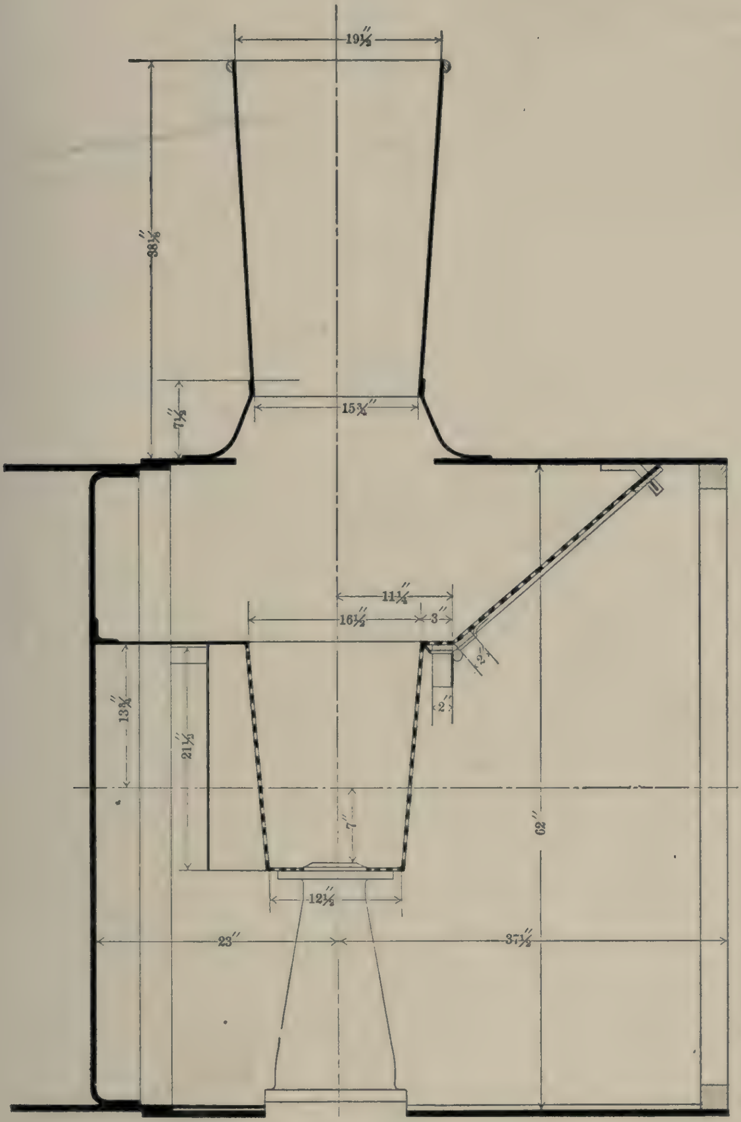


FIG. 26.

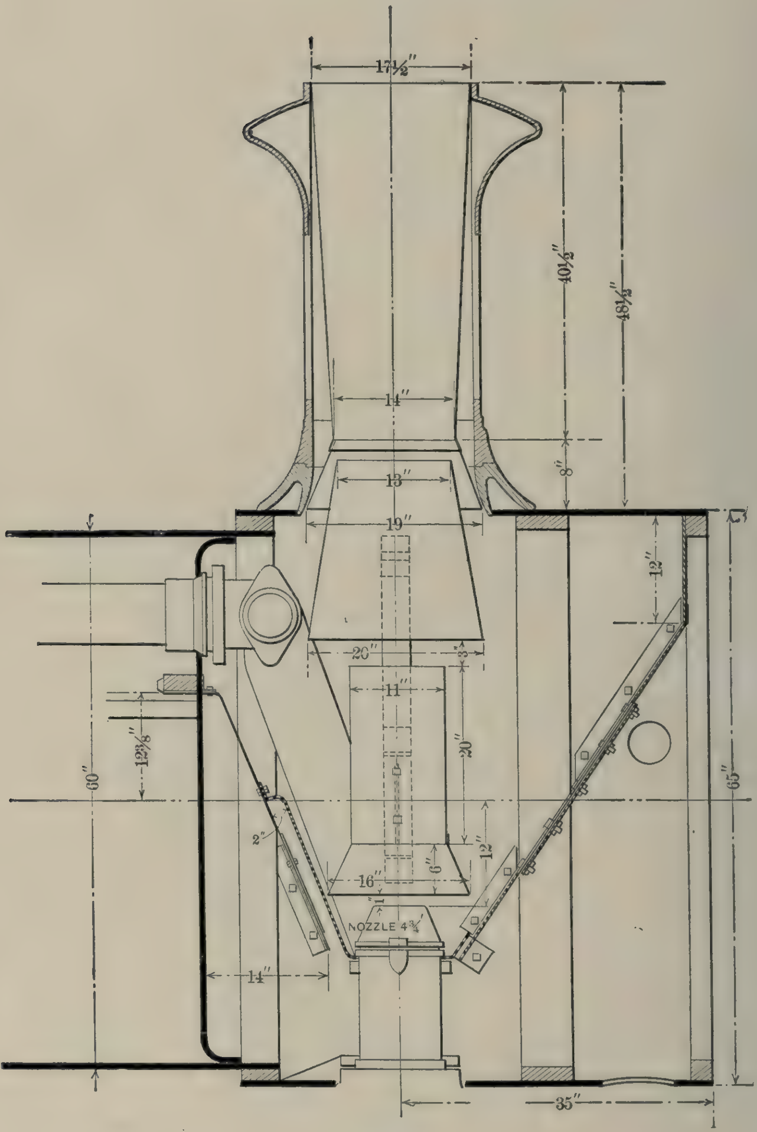

17½″
40½″
48½″
14″
8″
13″
19″
12″
20″
3″
11″
12⅜″
60″
20″
65″
2″
12″
6″
16″
1″
NOZZLE 4¾″
14″
35″

FIG. 27.

connect with the deflector, there being an unobstructed space of 17 inches between them. Mr. Johnstone of the Mexican Central in writing to Mr. Bell of this front-end says:

"You will see that we are using the master mechanics' standard nozzle and petticoat arrangement, with what we call the Mexican Central standard deflecting-plate and netting arrangement. This gives a clear opening between the bottom of the netting and the top of the deflecting-plate of 17 inches." To this Mr. Bell adds that "present practice in front-ends is plainly marked in the abandonment of the long-extended smoke-box by the Pennsylvania railroad in its latest and most approved designs of locomotives, for both fast passenger and heavy freight service. Figs. 30 and 31 show the front-end arrangement of the large H 5 and H 6 consolidation engines, recently built by that company, and the same design, in all substantial particulars, is used on their latest construction of high-speed passenger engines."

"In view of the fact that this front is doubtless practically self-cleaning, and of the comparatively large diameter of the smoke-box, it may be suggested that it could, with advantage and without sacrificing any netting area, be further shortened, as, say, 10 inches or thereabouts. Again, if a cinder-pocket is believed to be desirable with this or any other design of front, it would seem that if its smoke-box opening were made oblong, with the greater dimension transverse to the engine, the free discharge of the cinders would be facilitated and the length of front necessary to accommodate it be diminished. Among other meritorious features of this design, attention may be called to the disposition of the netting, whereby as great an area as is practicable within a determined length of front is

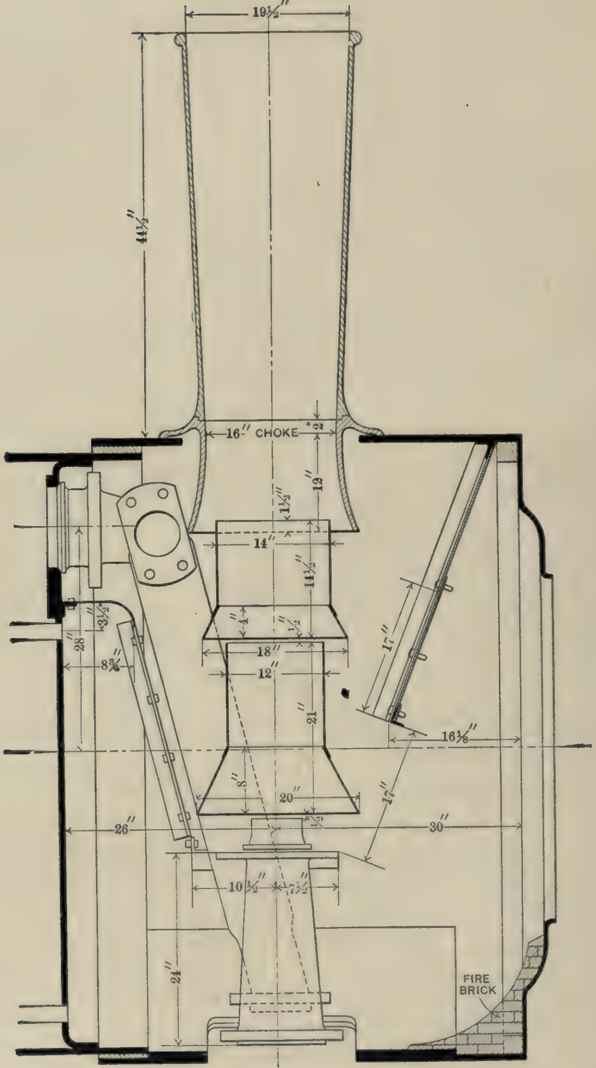

19½"
44½"
16" CHOKE
2"
13"
1½"
14"
14½"
4"
½"
18"
12"
21"
3½"
28"
8¾"
17"
16⅛"
8"
20"
½"
17"
26"
30"
10½"
7½"
24"
FIRE BRICK

FIG. 28.

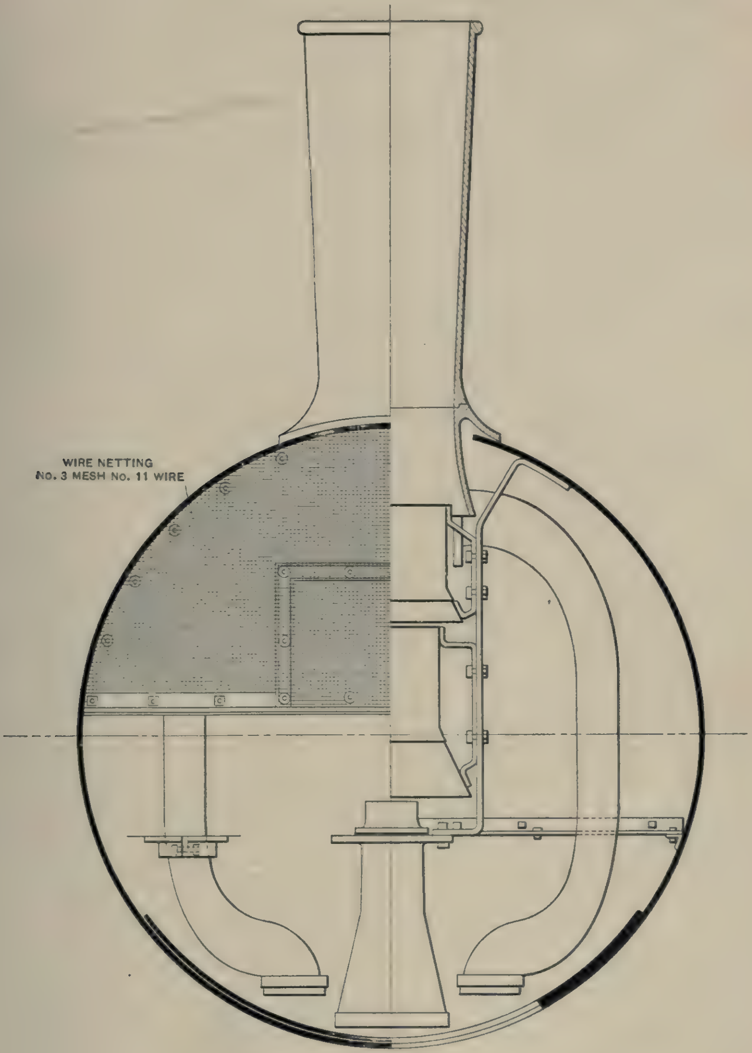


FIG. 29.

obtained, and the sheets are inclined relatively to the traverse of the escaping products of combustion. The inward extension of the stack, while by no means a novel feature, having been applied in English engines as early as 1860, is also believed by the writer to be of substantial practical value. There can be no doubt of the efficiency of this front, both as

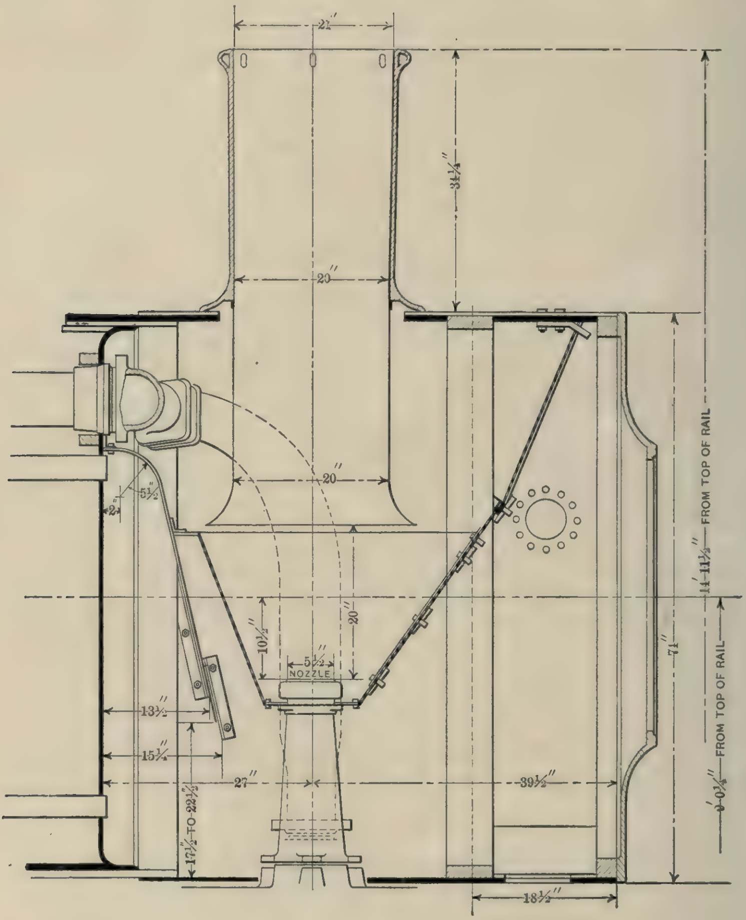


FIG. 30.

to free steaming and prevention of fire throwing, and it has been not an unimportant factor in the phenomenal performance of the E 1 passenger engines on the Camden & Atlantic Railroad."

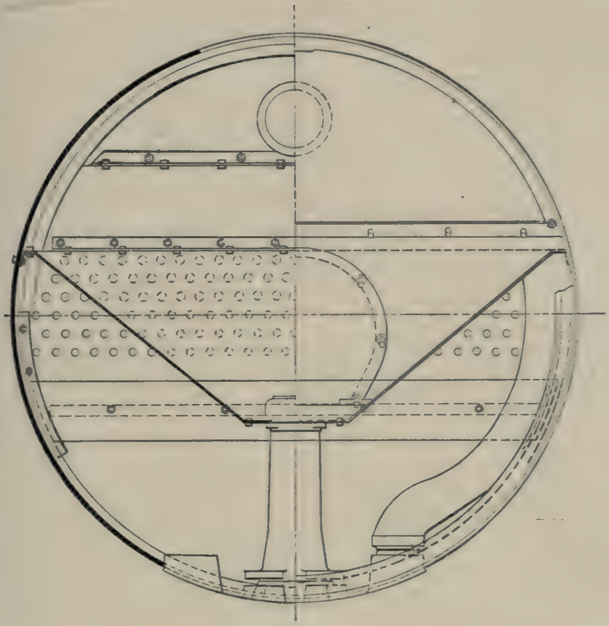


FIG. 31.

The Coburn front-end, which is shown in Figs. 32, 33, and 34, was designed by the late Mr. W. P. Coburn, of the Chicago, Indianapolis & Louisville Railway. It is designed to break up the sparks into fragments so small as to be incapable of doing damage, before they reach the stack. This is accomplished by a suitable arrangement of deflecting plate in connection with nests of long, closely set cast-iron spikes extending from the front door and head, rearward into the smoke-box. The current passing from the deflector-plate is sent upward into and

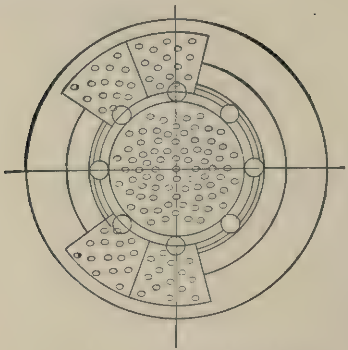


FIG. 34.

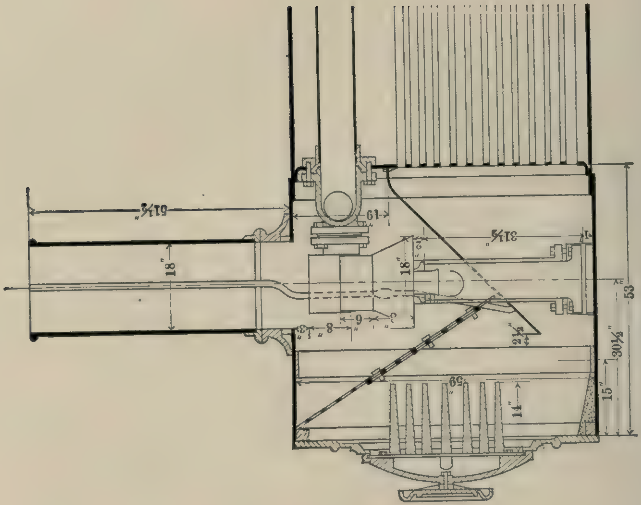


FIG. 33.

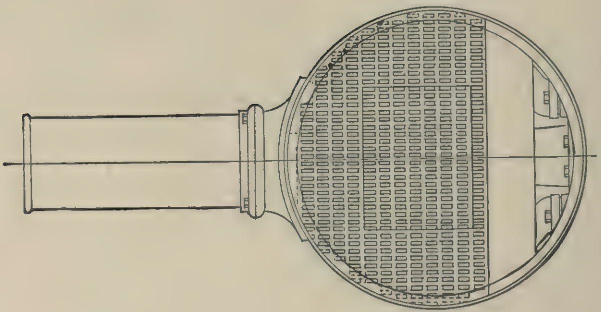


FIG. 32.

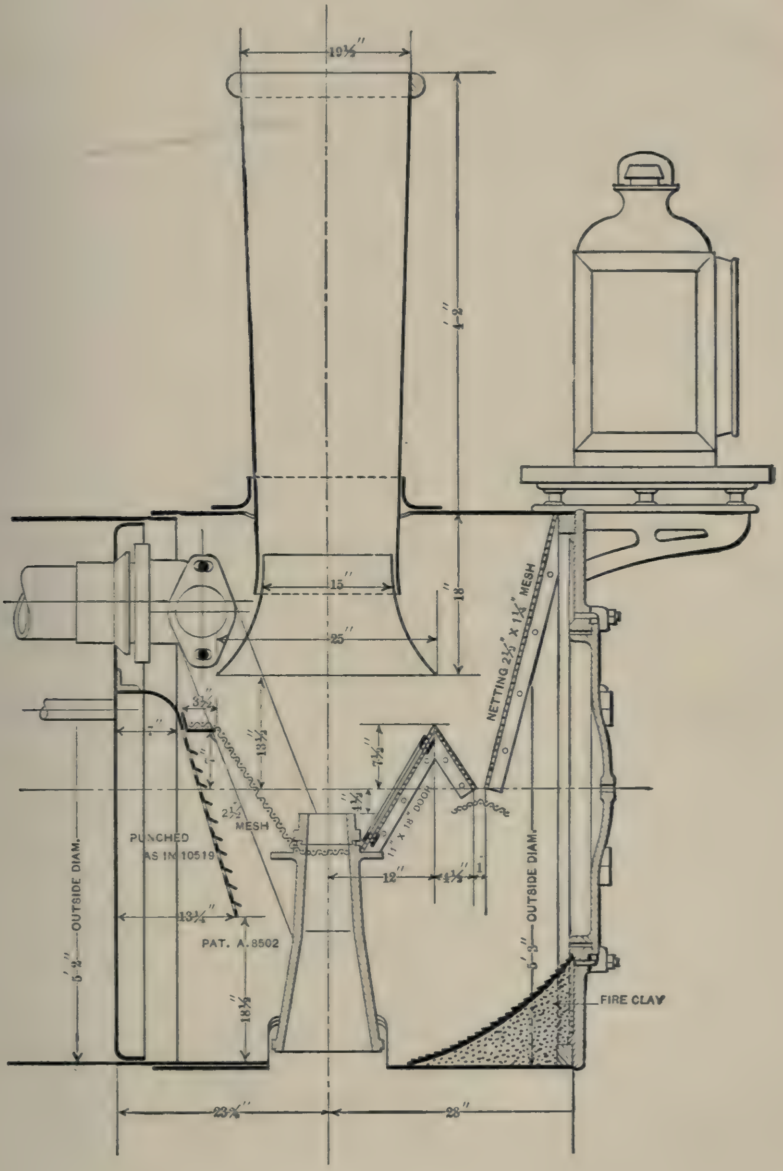

19½"
4'-2"
15"
25"
18"
3½"
13½"
7"
4"
2½"
MESH
PUNCHED
AS IN 10519
7½"
1½"
11" x 18" DOOR
12"
4½"
1"
NETTING 2½" x 1¼" MESH
13¼"
PAT. A.8502
18⅛"
5'-2" OUTSIDE DIAM.
5'-3" OUTSIDE DIAM.
FIRE CLAY
23⅞"
28"

FIG. 35.

through the nests of spikes already referred to. In making the passage, the cinders are made to impinge against the spikes which are set in their way, and are thereby pulverized to the desired degree of fineness. Obviously, this front-end is self-cleaning.

"The Bell front-end as in service in 21 × 26-inch consolidation engines on the Baltimore & Ohio Railroad is shown in Fig. 35. In later applications, on this road and on the Pittsburgh, Bessemer & Lake Erie Railroad, an addition has been made to the lower end of the deflecting-plate, extending, on a slight incline to a line in front of the exhaust-pipe, on the same principle as that of the self-cleaning fronts before referred to. The deflecting-plate is punched, with lips projecting toward the front from the holes, and a sheet of netting is placed in front of it to intercept any cinders that may pass through the holes. The main portion of the netting is set in three planes or in "saw-tooth" form in front of the exhaust-pipe, so as to present approximately vertical surfaces to the cinders as they pass up from below the deflecting-plate, and a 1-inch clear opening, protected by a lower sheet of netting, is left between the two front inclined sheets to prevent clogging by accumulation of cinders between them."

27. Authorities on the Front-end.—Those who may wish to make a more extended study of front-end arrangements will find an abundance of material. If interested in the proportions which give maximum efficiency to details of usual form, they should become familiar with the results of the very elaborate series of experiments which will be found of record in the Report on Exhaust-pipes and Steam-passages, Proceedings of the Master Mechanics' Association, 1896. These experiments were broadly planned and faithfully executed under the direction of Mr. Robert Quayle, Chairman of the Committee, assisted by Mr. E. M. Herr. The work was made to involve a full-sized locomotive so arranged that the desired data could be obtained with a degree of accuracy which inspires confidence in the general conclusion formulated by the committee. Another elaborate series of experiments designed to serve the same end, but involving quite a different plan of procedure, was conducted under the direction of Herr von Borries and Inspector Troske of the Prussian State Railway. An account of these experiments, translated from the German, was published in this country as a series of articles by the *American Engineer*. These appeared in ten of the twelve issues for the year 1896.

In his report on Draft Appliances to the International Railway Congress, Paris, 1900, Mr. C. H. Quereau reviews both the work of the Master Mechanics' Committee and the von Borries-Troske experiments and gives in condensed form the conclusions which they justify.

Those who are more interested in different combinations of the details should read a paper entitled "Draft Appliances of the Locomotives Exhibited at the Columbian Exposition, Chicago," which was read by Mr. E. M. Herr before the November, 1893, meeting of the Western Railway Club; also a paper, "Locomotive Front-ends," by J. Snowden Bell, given before the Western Railway Club; and in this connection, also, Mr. Quereau's report to the International Railway Congress to which reference has already been made.

CHAPTER V.

ACTION OF THE EXHAUST-JET AND DISTRIBUTION OF SPARKS WITHIN THE FRONT-END.

28. Experiments to Determine the Character of the Exhaust-jet.—The action of the exhaust-jet, and the design and arrangement of the draft appliances, have, as previously noted, been carefully investigated by a committee of the American Railway Master Mechanics' Association.* That part of the work which related to the action of the exhaust-jet was carried on at the locomotive laboratory of Purdue University by methods which may be described as follows:

In line with the centre of the stack and exhaust-pipe, cast-iron sleeves were fastened to the outside of the smoke-box (Fig. 36). Through these were fitted pipes 1, 2, 3, 4, and 5, arranged to slide in and out across the smoke-box, and having their inner ends turned down to a fine tip with sharp edges bounding the orifices. The body of each pipe was graduated to tenths of inches, the scale reading from a reference-mark fixed to the sleeve on the outside of the smoke-box. If the zero of the scale were brought under the reference-mark, the inner edge of the pipe would be directly under the centre of the stack, and directly over the centre of the exhaust-pipe. It is obvious that if the tip of any pipe be surrounded by the jet of exhaust-steam, the velocity of the latter will tend to carry steam through the pipe and to discharge it into the atmosphere outside of the smoke-box. It can be shown also that the force which the steam would exert in its effort to pass the pipe is a function of its velocity; hence by observing the force or pressure the velocity may be calculated. Pressures were observed by having the outer ends of each sliding pipe connected by rubber tubing with one leg of a manometer or U-shaped glass tube which was fastened to the wall of the laboratory. These U tubes were partially filled with mercury, the displacement of which gave the pressure transmitted through the tube. If, for example, the tip of any particular pipe were in the jet of steam, its manometer would show pressure; if it were withdrawn from the jet, its manometer would indicate a vacuum.

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* Report on Exhaust-pipes and Steam-passages, Master Mechanics' Proceedings, 1896, pp. 58–143.

Besides these sliding pipes in the smoke-box, the stack was fitted with three pipes which had plain ends projecting beyond the inner wall about a quarter of an inch. These side orifices were each connected with a manometer. They served to show the extent of pressure or vacuum existing within the stack at points where they were attached. Their exact location is shown by the dimensions in Fig. 36.

The draft was measured by two different manometers, and was permanently registered by a Bristol recording-gage. Indicators were used to show the steam distribution in the cylinders, and a special indicator fitted with a light spring gave a fine record of the back-pressure line. This pressure was also recorded by a Bristol gage. A Boyer speed-recorder served as a means for maintaining constant speed conditions.

Observations were made as follows: Desired conditions of speed and steam-pressure having been obtained, the adjustable pipes (1, 2, 3, 4, and 5), Fig. 36, were withdrawn from the smoke-box sufficiently to bring them entirely clear of the exhaust-jet, usually to a distance of 4½ inches from centre of jet. Then, upon signal, all manometer-gages were read and all other observations taken, the readings being taken simultaneously. Each sliding pipe was then moved inward a tenth of an inch and readings repeated, after which they were moved another tenth, and so on until the tips of all the pipes reach the centre of the exhaust-jet. The readings thus obtained from the pipes 1, 2, 3, 4, and 5, Fig. 36, were entered upon a half-sized drawing representing a portion of the cross-section of the smoke-box, the position of each entry showing the exact location to which the numerical readings applied. Upon the diagram of pressures thus obtained lines were drawn through points showing neither vacuum nor pressure. These lines were assumed to represent the border of the steam-jet, and are the outside lines in Figs. 37 to 39. In a similar manner, lines were drawn inside of those just described, each line connecting points representing the same pressure. These also appear in Figs. 37 to 39, but the numbers given in connection therewith do not represent pressure, but velocity in feet per second, as calculated from the indications of the gages. Each line, therefore, represents a chain of particles which have the same velocity, the value of which, in feet per second, is shown by the figure attached thereto.

The three jets thus shown were obtained under the same conditions, except that the speed of the engine for Fig. 37 was 25 miles; for Fig. 38, 35 miles, and for Fig. 39, 45 miles per hour. The conditions of running were such that each increment of speed resulted in a larger volume of steam delivered, and consequently in a higher vacuum. The diagrams show that as the volume of steam delivered increases, the velocity of the jet increases and its spread diminishes, due, doubtless, to the

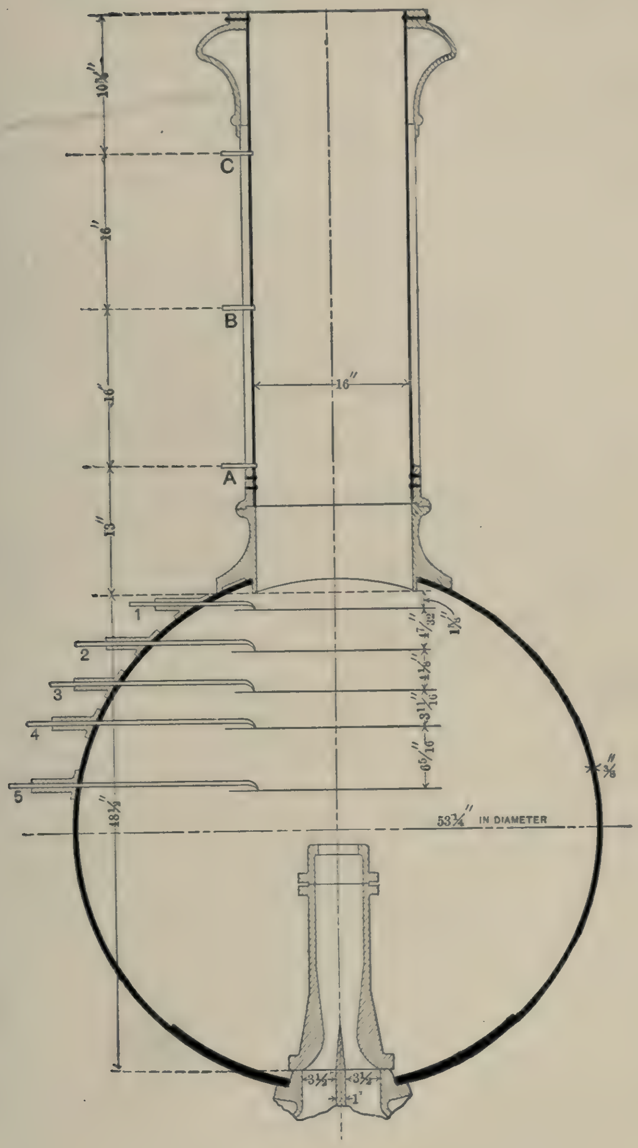
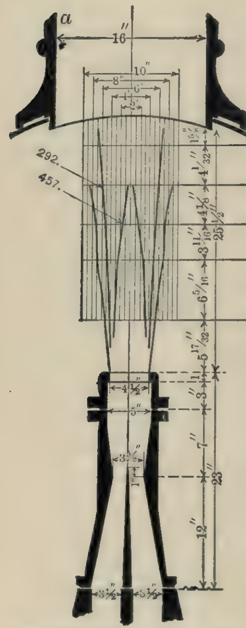

10¾"
C
16"
B
16"
16"
A
13"
1
2
3
4
5
18½"
4 7/32"
1⅜"
4⅛"
3 11/16"
6 5/16"
⅜"
53¼" IN DIAMETER
3½
3½
1"

FIG. 36.

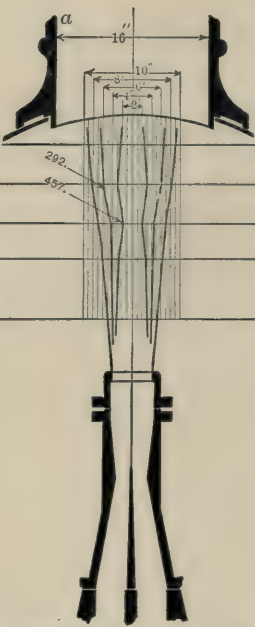
reaction of the body of smoke-box gases surrounding the jet. The velocity curves which in Fig. 38 are pretty evenly distributed throughout the body of the jet are in Fig. 39 crowded together, giving evidence in the latter case of a very dense and powerful jet.

The results derived from a large number of experiments similar in nature to that just described will be found presented in the Proceedings which have been referred to. From their study the following conclusions concerning the action of the jet appear to have been justified.



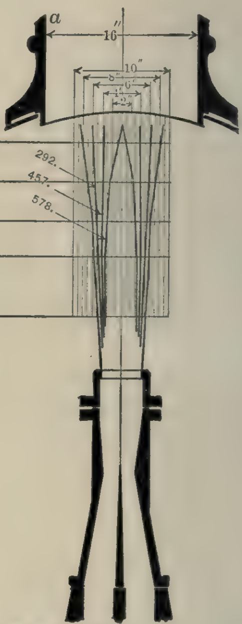
MILES PER HOUR	25
REVOLUTIONS PER MINUTE	135
POUNDS OF STEAM PER HOUR	6090

FIG. 37.



MILES PER HOUR	35
REVOLUTIONS PER MINUTE	188
POUNDS OF STEAM PER HOUR	8122

FIG. 38.



MILES PER HOUR	45
REVOLUTIONS PER MINUTE	242
POUNDS OF STEAM PER HOUR	8670

FIG. 39.

29. The Action of the Exhaust-jet. — Previous to the experiments just described it had usually been assumed that the action of the exhaust-jet is similar to that of a pump; that each exhaust supplies a ball of steam, which fills the stack very much as the piston of a pump fills its cylinder, and which pushes before it a certain volume of the smoke-box gases until it passes out at the top of the stack. The experiments disprove this theory. They show that the jet of steam does not fill the stack at or near the bottom; that under certain conditions common to practice it touches the stack only when it is very near the top; and, finally, that a jet of steam flowing steadily from the exhaust-tip, the engine being at rest, results in draft conditions which are in every way similar with those obtained with the engine running, the same amount of steam being discharged per unit of time in each case.

Enough has not yet been done to define the precise action of the jet, but it may be said with certainty (1) that it acts to induce motion in the particles of gas which immediately surround it, and also (2) that it acts to enfold and entrain the gases which are thus made to mingle with the substance of the jet itself.

The induced action, which, for the jets experimented upon, is by far the most important, may be illustrated by means of Fig. 40. The arrows in this figure represent, approximately, the direction of the currents surrounding the jets. It will be seen that the smoke-box gases tend to move toward the jet, and not toward the base of the stack, at which point they are to leave the smoke-box. That is, the jet, by virtue of its high velocity and by its contact with surrounding gases, gives motion to particles close about it, and these, moving on with the jet, make room for other particles which are farther away. As the enveloping shell of gas approaches the top of the stack,

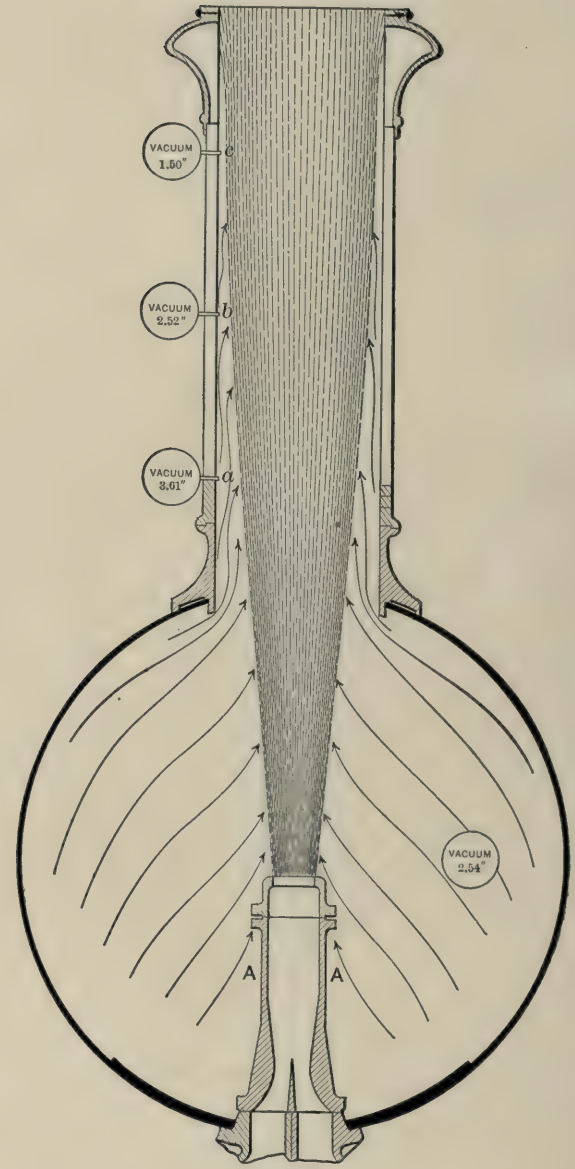


FIG. 40.

its velocity increases and it becomes thinner and thinner, all as shown by Fig. 40. All parts of the jet require gases to work upon the upper as well as the lower part. Gages attached to the side of the stack show a vacuum, because the gases needed for the upper portion of the jet can reach it only by coming in around the jet lower down. In other words, the action of the upper part of the jet induces a vacuum in the lower part of the stack, just as the action of the jet as a whole induces a vacuum in the smoke-box. It will be shown later that as the amount of work to be done by the exhaust is increased the jet becomes smaller, thus making room for larger volumes of gas to pass between it and the stack; the velocity both of the jet and of the induced currents increasing.

The Intermingling of the Smoke-box Gases with the Steam. That there is some intermingling of the smoke-box gases with the steam of the jet is made evident by the appearance of the combined stream as it issued from the top of the stack. The manner in which this intermingling takes place will be seen from the following considerations.

Any stream flowing from a nozzle through a resisting medium will have a higher velocity at its centre than at its circumference or sides. That is, the particles at the centre of the jet move at a higher velocity than those on the outside, the latter being held back by contact with the surrounding gas. The result of the different velocities in the same stream is a wave motion of the individual particles of which the stream is composed. Thus the path of any one of these particles may be shown by Fig. 41, *A*, but the exact form and frequency of the loops will depend upon the relation between these differences in the velocity of particles in different portions of the stream, and the actual mean velocity of the jet. If the velocity of the jet is high, and differences for different portions of the cross-section are not great, the loop may disappear, the path appearing as shown by Fig. 41, *B*. With a still higher mean velocity, and a smaller difference, the loops would approach

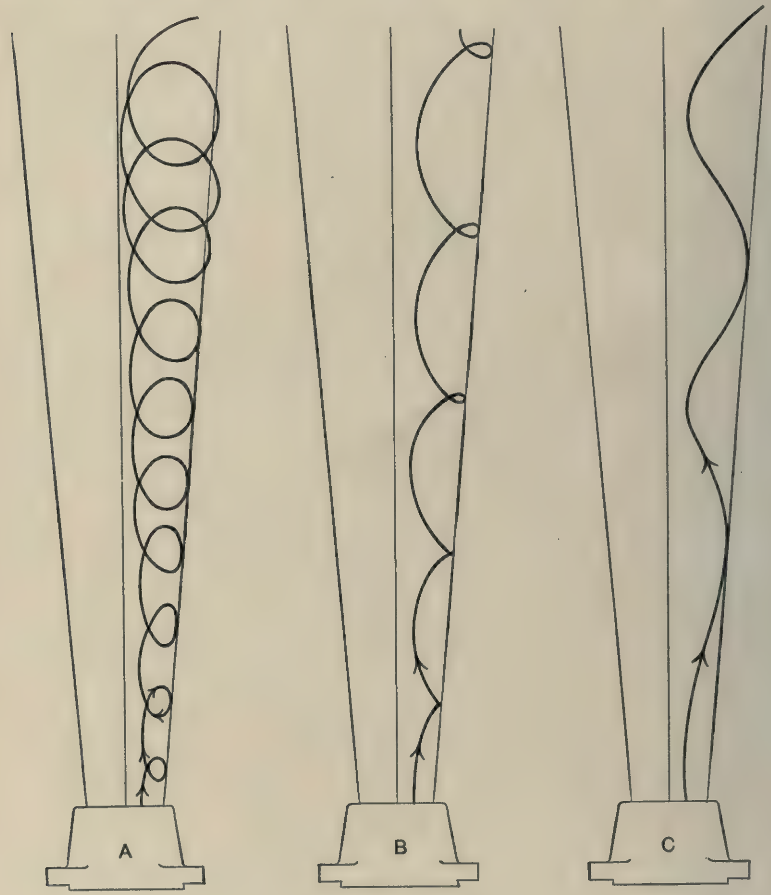


FIG. 41.

the form shown by Fig. 41, *C*. The exhaust-jet appears to take this latter form. Measurements to determine its velocity show that particles in the centre move much more rapidly than those near the outside, and other measurements to determine

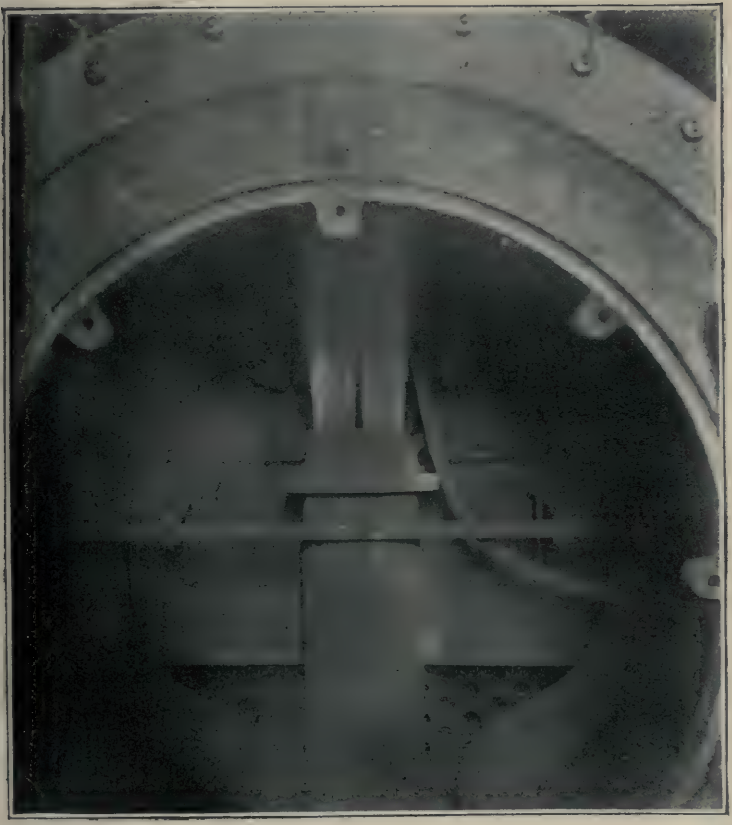


Fig. 42.

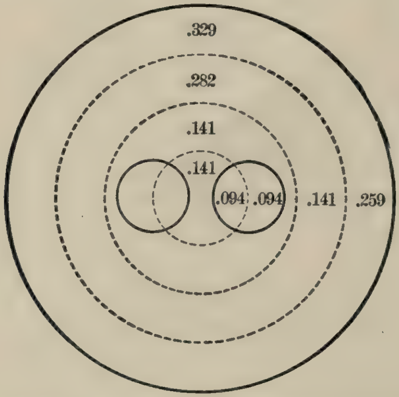
the form of the jet as a whole, define a boundary which is neither a straight line nor a regular curve, but which agrees closely with the form given by Fig. 41, *C*. All this shows that the jet is stepped off in nodes, which under given conditions remain fixed in position. This conclusion, based upon measurements of the jet, is confirmed by the appearance of the jet as seen in an engine running with the front-end open. The jet when thus viewed exhibits one or more bright spots which remain in a fixed position. It is through the wave action of the particles making up the steam-jet that the surrounding gases are enfolded and intermixed with the steam of the jet.

It is clear that any design of nozzle which will serve to subdivide the stream, or to spread it so as to increase its cross-section, will assist the jet in its effort to entrain the gases, but it is not clear that there is any gain in efficiency to be realized in such a result. It is possible that, as the mixing action is increased, the induced action may be diminished, and that the sum total of the effect produced may remain nearly constant. The work which has thus far been done is not conclusive on this point, but the evidence tends to show that the more compact and dense the jet the higher its efficiency. It is certainly clear that, for the jets experimented upon, the mixing action is hardly more than incidental to the induced action, the latter constituting the influence through which the work of the jet is chiefly accomplished.

In connection with the diagrams Figs. 37 to 39, Fig. 42, which is from a photograph of the jet delivered from a double nozzle, will be of interest. The view represents what one sees when looking into a front-end when the locomotive is being run with the front door open.

30. Distribution of Sparks within the Stack.—Designers of draft appliances, being confronted with the problem of intercepting the sparks at some point between the front tube-sheet and the top of the stack, will be helped in this work by a knowledge of the course taken by the sparks. It is thought proper, therefore, to make of record such information upon this point as has been derived from certain investigations, some features of which have already been discussed. For the purpose of such a presentation the data as obtained for Test No. 4, Table I, Chapter III, have been selected as fairly representative of the general conditions.

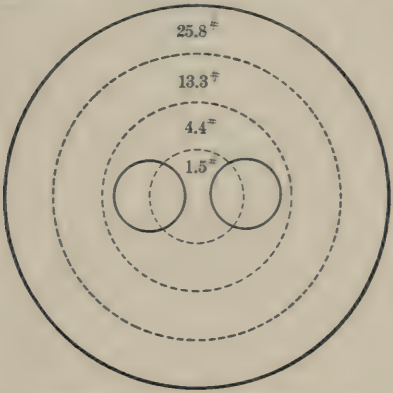
Sparks passing through a square-inch section of the stack at various points are indicated in position and value by the numerals given in Fig. 43. It will be seen that the weight diminishes steadily as the positions of observation are changed from the outside to points nearer the centre, and also that those points which are most remote from the action of the exhaust-jet show the largest weight of sparks. Fig. 44 gives the weight of sparks per hour for the several annular rings into



POUNDS OF SPARKS PASSING OUT OF STACK PER SQUARE INCH OF STACK AREA PER HOUR AT THE VARIOUS PLACES DESIGNATED. THE TWO FULL CIRCLES INDICATE THE SIZE AND LOCATION OF THE DOUBLE EXHAUST-TIP.

FIG. 43.

which the area of the stack is assumed to be divided; the breadth of each ring being 2 inches. Here, again, the fact that the sparks follow the wall of the stack rather than the centre of the stream is disclosed; more than 50 per cent of the whole weight being credited to an area embraced by a ring 2 inches broad measured from the outside circumference of the



POUNDS OF SPARKS PASSING OUT OF STACK PER HOUR IN THE SEVERAL AREAS INDICATED.

FIG. 44.

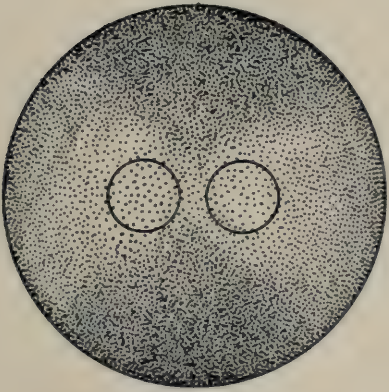


FIG. 45.

stream. The distribution of sparks in the stack is shown graphically by Fig. 45. This figure may be accepted as a correct graphical presentation of the comparative density of the sparks throughout all portions of the cross-section of the stack.

The conclusion concerning distribution is that the sparks follow most readily those portions of the stream issuing from the stack which have the lowest velocity, which conclusion is entirely consistent with the information already presented regarding the action of the exhaust-jet. It should be noted, however, that these observations were made on a cross-section of the stream at a point immediately after it issued from the stack, and may not represent conditions actually existing in the stack.

CHAPTER VI.

SPREAD OF SPARKS FROM LOCOMOTIVES AS DISCLOSED BY OBSERVATIONS ALONG THE RIGHT-OF-WAY.

THE preceding chapters have served to show that all locomotives when working under normal conditions discharge particles of ash and fuel from the top of their stacks. It has been shown that the fuel-value of the material thus discharged is considerable. We are now to consider what is the distribution of the material discharged over the surface of the ground in the immediate vicinity of the track, and what liability there is of fire arising from its presence.

31. Experiments and Results.—To secure information covering this point, investigations under the direction of the author were first undertaken by Mr. George F. Mug, M.E.,* who made observations both at the Purdue experimental locomotive and along the right-of-way. While Mr. Mug obtained much valuable data, his efforts were largely given to the developments of methods of procedure. In this he was so successful that subsequent investigations have been based upon his work. The most elaborate data thus far obtained are those of Messrs. Ducas and Dill, from whose thesis † the facts of this chapter are chiefly drawn.

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* "A Study of the Cinder- and Spark-losses in Locomotives," a thesis by George F. Mug, B.S., candidate for the degree of M.E., Purdue University, June, 1896.

† "Spark-losses from Locomotives on the Road," a thesis by J. B. Dill and Charles Ducas, candidates for the degree of B.S., Purdue University, June, 1900.

The method employed may be described as follows: ten metal pans 22 inches square were placed in line at right angles to the track from 10 to 100 feet apart, and on the leeward side, all as indicated by Fig. 46. The exact distance of each pan from the centre of the track is shown by Table V, and a view of the field with the pans in position by Fig. 47. The pans were placed on one side or the other of the track, depending upon

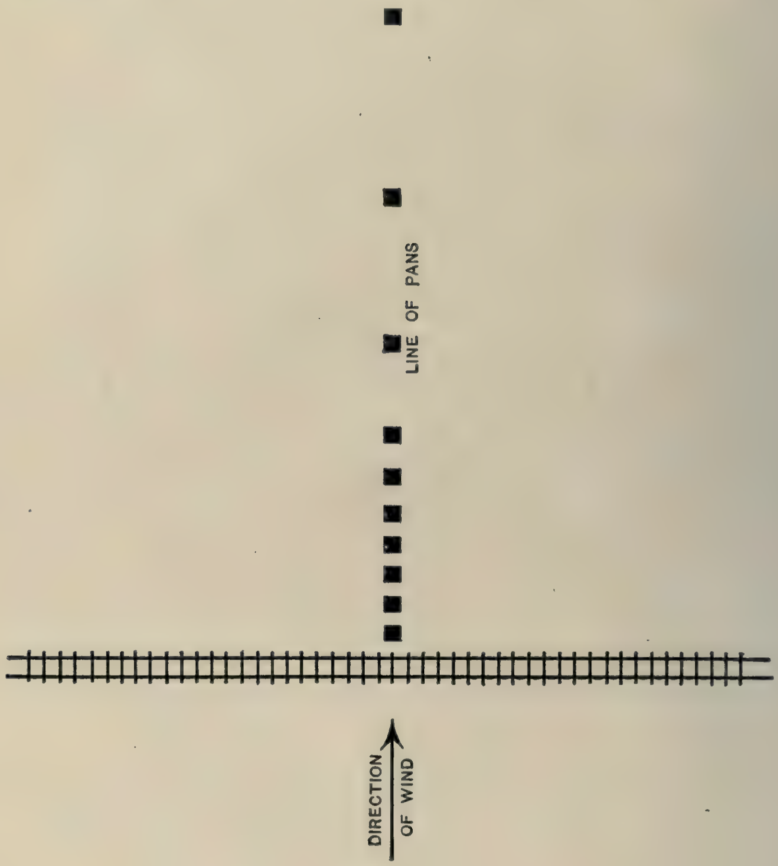


Fig. 46.

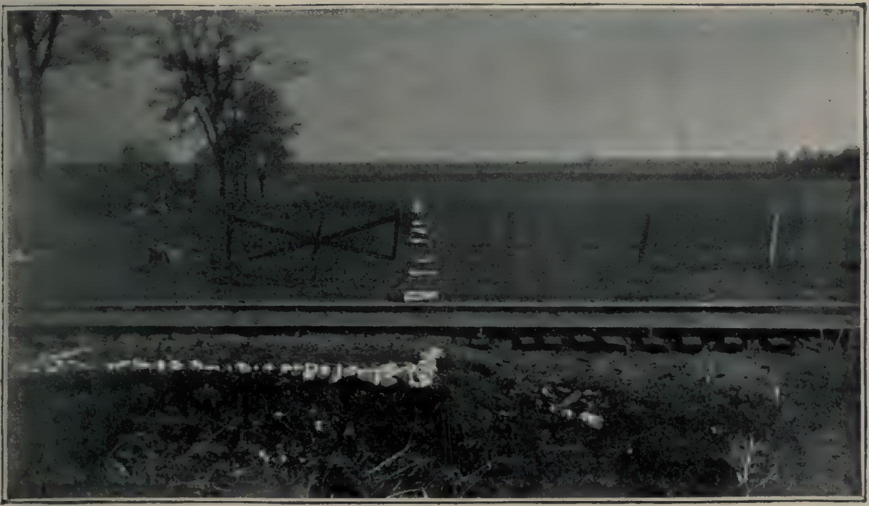


Fig. 47.

TABLE V.

Number of Test.	Distances of Pans from Centre of Track in Feet.									
1, 2, 3	15	25	35	45	70	100	150	200	250	350
4, 5, 6, 7, 8, 9	20	35	50	65	80	100	125	175	250	350
10, 11, 12, 13, 14	20	40	60	80	100	125	160	200	250	350

whether the wind was from the north or the south. A layer of cotton in the bottom of each pan served to retain sparks which otherwise might have been blown away by the wind, and was expected to indicate by a scorched mark the degree of heat in the spark. The place selected for conducting the tests was at the top of a grade on the Lake Erie & Western Railroad, at a point about two miles west of the Lafayette station. A profile of the road in this vicinity is given as Fig. 48. The section of track involved is used jointly by the L. E. & W. R. R. and by the Big Four Company, all Indianapolis and Chicago trains of the latter company passing over it. It is to be noted that, from the start at the station, locomotives have a heavy pull all the way to the point where the observations were made, with heavy grades still beyond. They were therefore invariably working very hard when passing the point of observation. Observations were made only on those trains which came up the grade. When others passed the pans were covered.

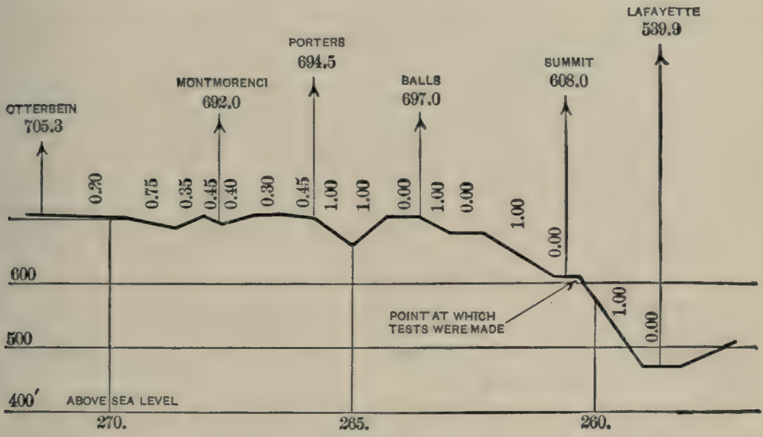


FIG. 48.

The observations were such as served to make of record the direction of wind, velocity of wind, temperature of the atmosphere, character of train (whether freight or passenger), number of cars in train, time required to pass between two stakes set at a known distance apart, type, name and number of locomotive, and character of smoke (light, dark, very dark, or black). From the observed time in passing between the two stakes the speed of the train was calculated. A photograph of each train was also taken. After the train had passed, all the sparks caught in each pan were carefully collected, placed in a separate bottle, and properly labelled.

Table VI presents a summary of the general observations obtained during the progress of the tests. It is to be noted that most of the freight trains were run with a "pusher" in the rear, and the sample sparks collected represent the discharge from two engines. The tests include conditions for which the wind velocities varied from a little over five miles per hour to nearly twelve miles per hour.

The weight of sparks caught in each pan for each test, as well as the weight falling upon an area of 10 × 10 feet for which each pan is the geometrical centre, as calculated from the weight collected in the pan, is given in Tables VII and VIII. All weights are in grammes. From the fourteen different tests which were made, six have been selected as typical, to be made the subject of a more detailed description. The results of these fairly represent the whole series. They are so selected as to include the full range of conditions which were obtained. The collection from each pan for the six tests selected is shown in detail in pages 110 to 127. The sketches represent the actual size and shape of all the sparks caught in each pan for the several tests under consideration. Tests Nos. 2 and 10 are those for which the spread of sparks is greatest; Tests Nos. 5 and 6, those for which it is of average extent; and Tests Nos. 8 and 14, those for which it is least. In Tests Nos. 2 and 10 the greatest weight of sparks is found

TABLE VI.

SUMMARY OF GENERAL OBSERVATIONS. SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.

No. of Test.	Date of Test.	Hour.	Direction of Wind.	Velocity of Wind. Miles per Hour.	Temperature of Atmosphere. Degrees F.	Character of Train.	No. of Cars.	Time Required to Pass Measured Distance. Seconds.	Speed of Train. Miles per Hour.	Type of Locomotive.	Locomotive Number.	Name on Locomotive	Character of Smoke.
1	Apr. 16	3.18 P.M.	South	11.9	57	Freight	28	14.0	14.5	Mogul	35	Nor. Ohio	Black
2	“ “	3 35 “	“	11.6	“	“	29	13.0	15.7	10-Wheeler	472	Big 4	“
2	“ “	“ “	“	“	“	“	“	“	“	“	270	“	Dark
3	“ “	5.00 “	“	9.6	“	Passenger	3	5.4	37.8	American Passenger	52	L. E. & W.	“
4	“ 21	10,45 A.M.	S.W.	9.3	60	“	4	8.0	29.8	“ “	39	“	“
5	“ “	11.15 “	“	8.7	“	Freight	34	15.8	15.1	10 Wheeler	429	Big 4	Light
5	“ “	“ “	“	“	“	“	“	“	“	“	270	“	Dark
6	“ “	1 25 P.M.	“	9.8	“	“	11	10.0	23.3	American Passenger	109	L. E. & W.	“
7	“ “	1.50 “	“	8.2	“	Passenger	5	8.0	29.3	“	115	Big 4	Light
8	“ “	3.25 “	“	7.0	“	Freight	12	11.0	21.6	Mogul	54	L. E. & W.	Dark
9	“ “	5.08 “	“	5.1	“	“	29	13.5	17.6	10-Wheeler	399	Big 4	Very black
9	“ “	“ “	“	“	“	“	“	“	“	“	270	“	Black
10	“ 23	9.37 A.M.	N.	7.9	68	“	34	16.0	14.9	Mogul	34	Nor. Ohio	“
10	“ “	“ “	“	“	“	“	“	“	“	“	54	L. E. & W.	“
11	“ “	10.55 “	“	8.7	“	Passenger	4	8.0	29.8	American Passenger	51	“	Dark
12	“ “	11.15 “	“	9.7	“	Freight	30	14.0	17	10-Wheeler	436	Big 4	Black
12	“ “	“ “	“	“	“	“	“	“	“	“	270	“	Dark
13	“ “	1.50 P.M.	“	10.5	“	Passenger	6	6.0	39.7	“	186	“	“
14	May 5	2.04 “	“	8.9	70	Freight	30	13.0	18.3	“	463	“	Very black
14	“ “	“ “	“	“	“	“	“	“	“	“	270	“	Dark

TABLE VII.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD WHEN TRAINS WERE PULLED BY SINGLE LOCOMOTIVE.

Test Number.	1										3									
Distance of pans from centre of track. Feet.	15	25	35	45	70	100	150	200	250	350	15	25	35	45	70	100	150	200	250	350
Weight of sparks caught in each pan. Grammes.	.0000	.0155	.0040	.0010	.1620	.1775	.0090	.0055	.0020	.0005	.0000	.0007	.0068	.0495	.0273	.0020	.0013	.0000	.0000	Trace
Equivalent weight of sparks per 100 square feet. Grammes.......	.0000	.4495	.1200	.0294	5.022	5.325	.2610	.1705	.0600	.0150	.0000	.0203	.2040	1.855	.8463	.0600	.0377	.0000	.0000	....
Test Number.	4										6									
Distance of pans from centre of track. Feet.	20	35	50	65	80	100	125	175	250	350	20	35	50	65	80	100	125	175	250	350
Weight of sparks caught in each pan. Grammes	.0075	.0245	.0118	.0009	.0009	Trace	.0020	.0010	Trace	.0000	.0005	.0335	.0585	.2810	.1824	.1074	.0130	.0015	Trace	Trace
Equivalent weight of sparks per 100 square feet. Grammes.......	.2213	.7105	.3540	.0265	.0279	......	.0580	.0310	....	.0000	.0148	.9715	1.755	8.261	5.654	3.222	.3770	.0465	.. ...	......
Test Number.	7										8									
Distance of pans from centre of track. Feet.	20	35	50	65	80	100	125	175	250	350	20	35	50	65	80	100	125	175	250	350
Weight of sparks caught in each pan. Grammes	.0110	.0021	.0965	.3055	.0565	.0020	.0020	Trace	Trace	Trace	.1979	.0912	.0635	.0150	.0032	.0040	.0022	.0008	.0008	Trace
Equivalent weight of sparks per 100 square feet. Grammes........	.3245	.0609	2.895	8.982	1.752	.0600	.0580	....	....	.....	5.838	2.645	1.905	.4410	.0992	.1200	.0638	.0248	.0240	.....
Test Number.	11										13									
Distance of pans from centre of track. Feet.	20	40	60	80	100	125	160	200	250	350	20	40	60	80	100	125	160	200	250	350
Weight of sparks caught in each pan. Grammes	.0055	.1076	.5060	.0510	.0495	.0105	.0020	.0005	.0015	Trace	.0439	.0860	.0288	.0055	.0030	Trace	.0000	.0000	.0000	.0000
Equivalent weight of sparks per 100 square feet. Grammes........	.1623	3.120	1.518	1.499	1.535	.3150	.0580	.0155	.0450	.. ...	1.295	2.494	.8640	.1617	.0930	......	.0000	.0000	.0000	.0000

1 gramme = .0035 ounce.

TABLE VIII.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD WHEN TWO LOCOMOTIVES WERE USED ON TRAIN.

Test Number.	2										5									
Distance of pans from centre of track. Feet.	15	25	35	45	70	100	150	200	250	350	20	35	50	65	80	100	125	175	250	350
Weight of sparks caught in each pan. Grammes	Trace	.0105	.0550	.0770	.2825	.2401	.0700	.0094	.0035	.0037	.0150	.1913	.4139	.0390	.0125	.0043	.0058	.0014	.0005	Trace
Equivalent weight of sparks per 100 square feet. Grammes......	.....	.3045	1.650	2.634	8.758	7.203	2.030	.2914	.1050	.1110	.4410	5.548	12.42	1.147	.3875	.1290	.1682	.0434	.0150	......
Test Number.	9										10									
Distance of pans from centre of track. Feet.	20	35	50	65	80	100	125	175	250	350	20	40	60	80	100	125	160	200	250	350
Weight of sparks caught in each pan. Grammes	.1735	.0023	.0006	.0032	.0008	.0005	.0000	Trace	.0000	.0000	.0035	.0170	.1459	.4800	.1340	.0405	.0114	.0053	.0026	Trace
Equivalent weight of sparks per 100 square feet. Grammes... ...	5.118	.0667	.0180	.0941	.0248	.0150	.0000	......	.0000	.0000	1.053	.0493	4.377	14.11	.4154	.1215	.3306	.1643	.0780	......
Test Number.	12										14									
Distance of pans from centre of track. Feet.	20	40	60	80	100	125	160	200	250	350	20	40	60	80	100	125	160	200	250	350
Weight of sparks caught in each pan. Grammes	.0350	.1280	.2390	.0200	.0150	.0080	.0031	.0017	.0012	Trace	.0650	.3117	.2375	.1877	.0242	.0140	.0060	.0051	.0075	.0005
Equivalent weight of sparks per 100 square feet. Grammes... .	1.033	3.712	7.170	.5880	.4650	.2400	.0899	.0527	.1360	.....	1.918	9.039	7.125	5.518	.7502	.4200	.1740	.1581	.2250	.0150

1 gramme = .0035 ounce.

at 70 and 80 feet from the track, respectively; in Tests Nos. 5 and 6 the greatest weight is found at 50 and 65 feet, respectively; and in Tests Nos. 8 and 14 the greatest weight is at 20 and 40 feet, respectively.

It will be of little value to attempt to compare one test with another, even though the conditions as to wind may be apparently the same. Such a comparison would only lead to flagrant inconsistencies. It will be shown in a subsequent chapter that the distance traversed by a spark after leaving the stack is dependent in part on the initial upward impulse received. This in turn is dependent on conditions within the locomotive itself, and concerning which no information could be made of record. It is, therefore, but reasonable to expect that even under like conditions of wind the distribution of sparks for individual tests may be widely different, and the results show that such a condition actually exists.

To better show the distribution of sparks, the weight caught in each pan for each of the six typical tests is shown graphically by Figs. 50, 52, 54, 56, 58, and 59.

In connection with the diagrams, photographs of the head of the several trains involved by the tests are given as Figs. 49, 51, 53, 55, and 57, each of the six tests being represented excepting No. 8, for which the photograph failed. The photographs indicate something of the heavy service which the locomotives were performing, also something of the direction and velocity of the wind. It would seem that the total weight of sparks discharged by the locomotives shown, under the conditions which have been described, must have been nearly maximum for any locomotive in good condition. With higher wind velocities the sparks might be spread over somewhat greater distances, but it is hardly likely that they would ever be more thickly strewn or that the relation of size to distance from track would be greatly changed.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.
TEST NO. 2. TRAIN WITH "PUSHER."

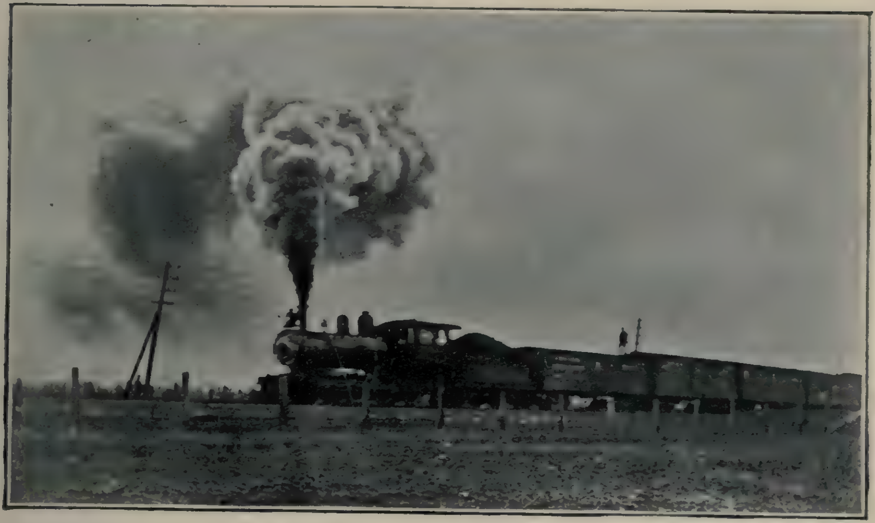


FIG. 49.—One of the two locomotives during the test, the record for which is given below.

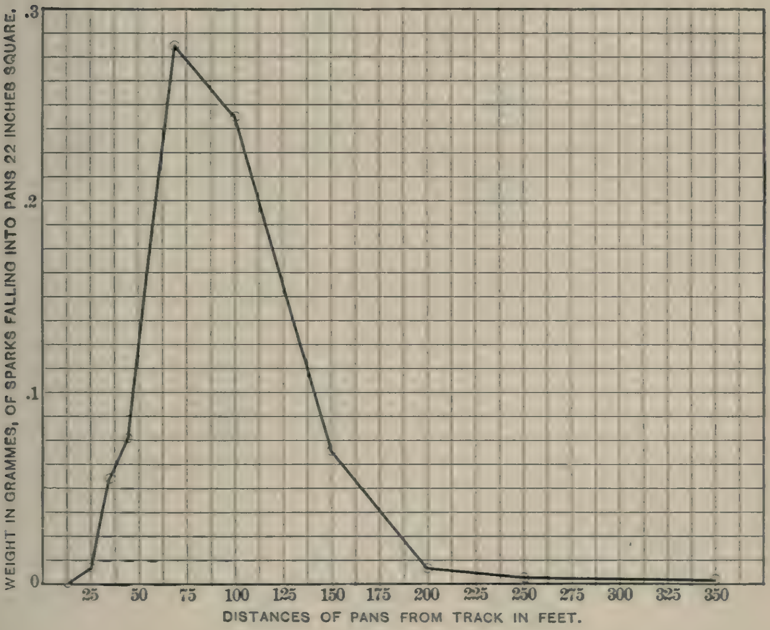


FIG. 50.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.
TEST NO. 10. TRAIN WITH "PUSHER."

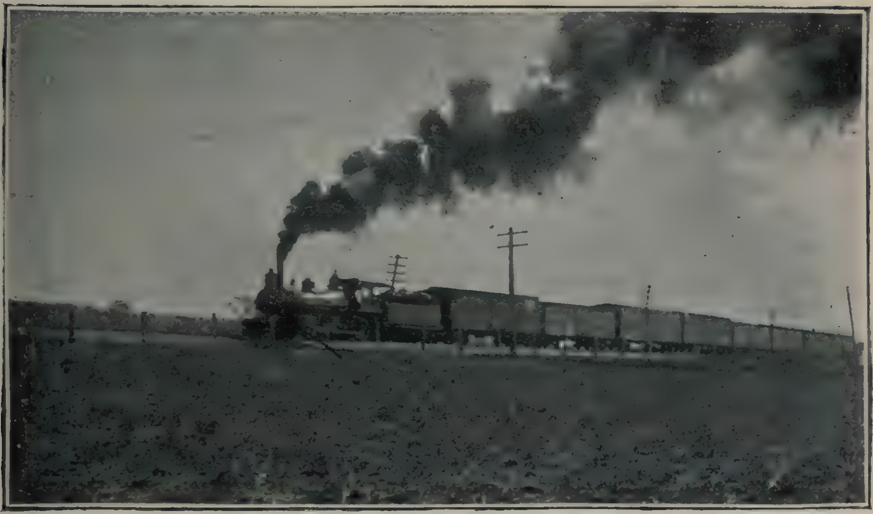


FIG. 51.—One of the two locomotives during the test, the record for which is given below.

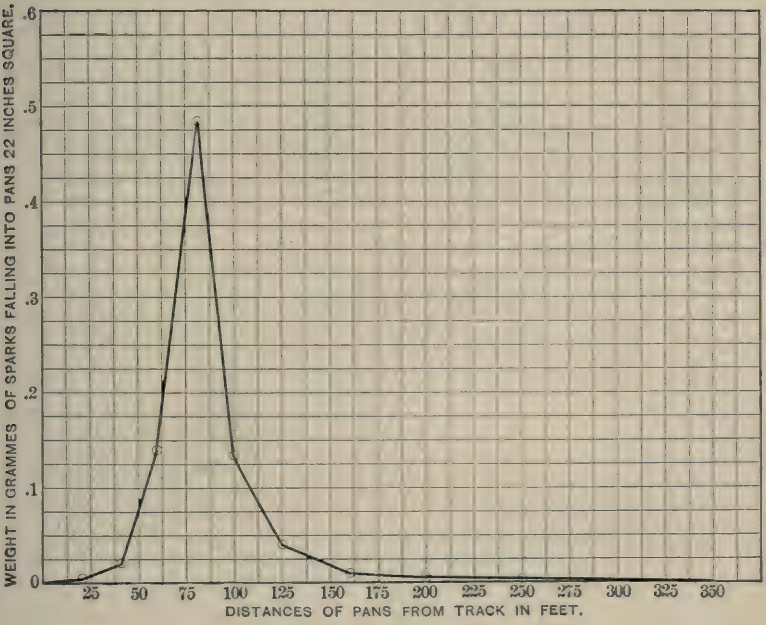


FIG. 52.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.
TEST NO. 5. TRAIN WITH "PUSHER."

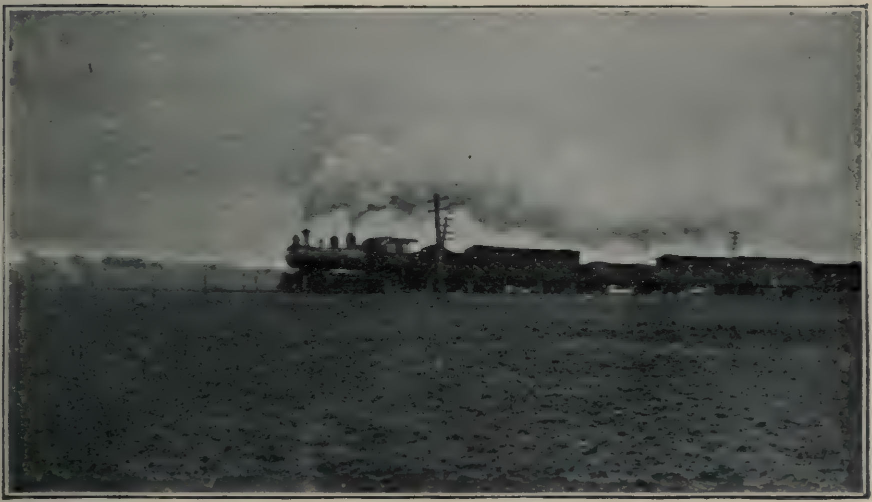


FIG. 53.—One of the two locomotives during the test, the record for which is given below.

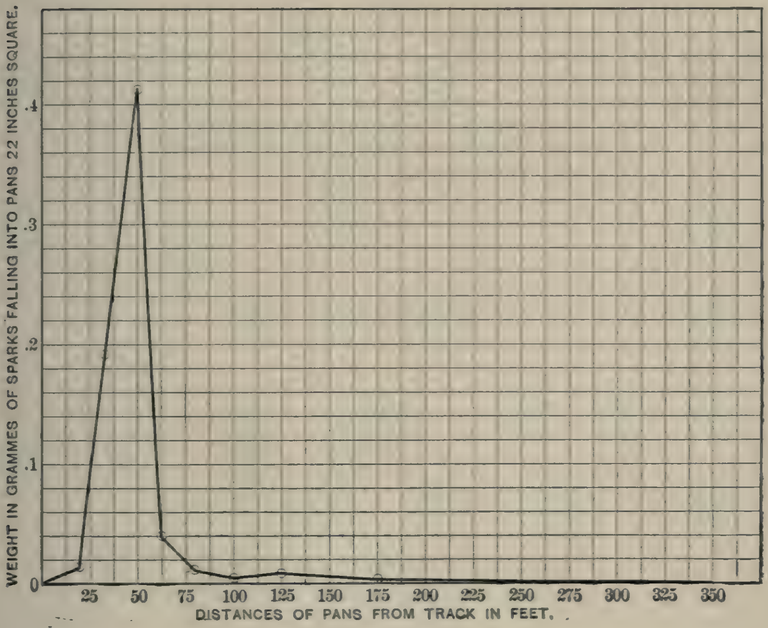


FIG. 54.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.
TEST NO. 6.

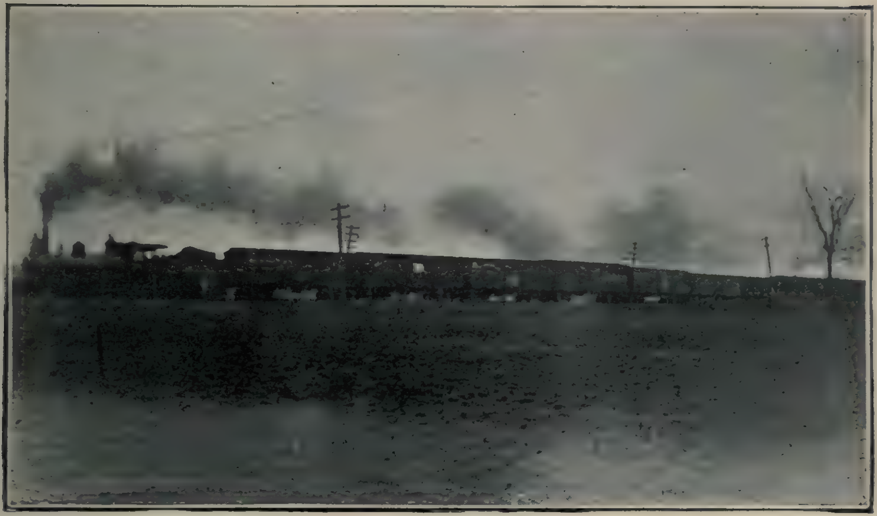


FIG. 55.—The locomotive during the test, the record for which is given below.

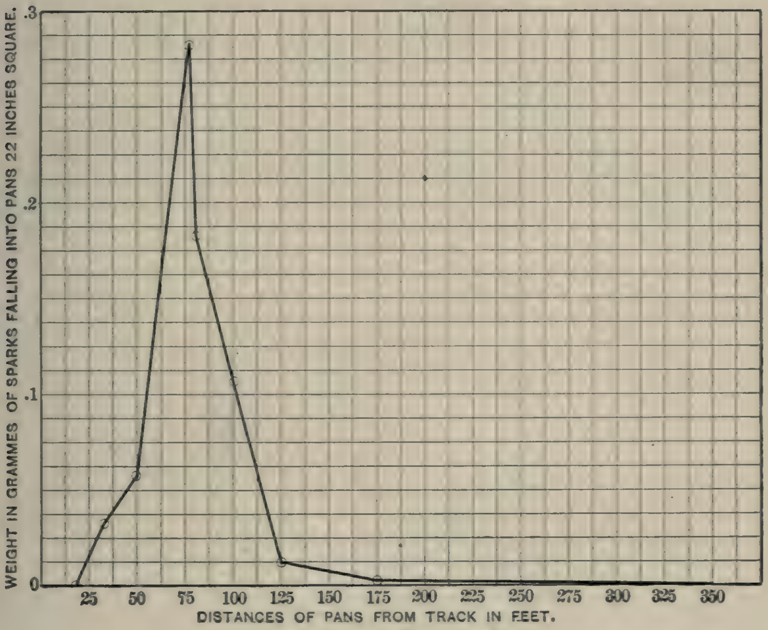


FIG. 56.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.
TEST NO. 14. TRAIN WITH "PUSHER."

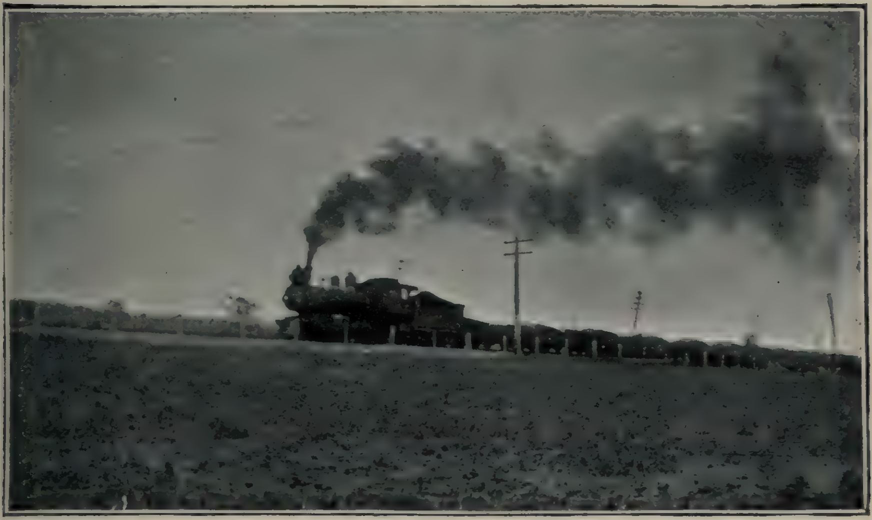


FIG. 57.—One of the two locomotives during the test, the record for which is given below.

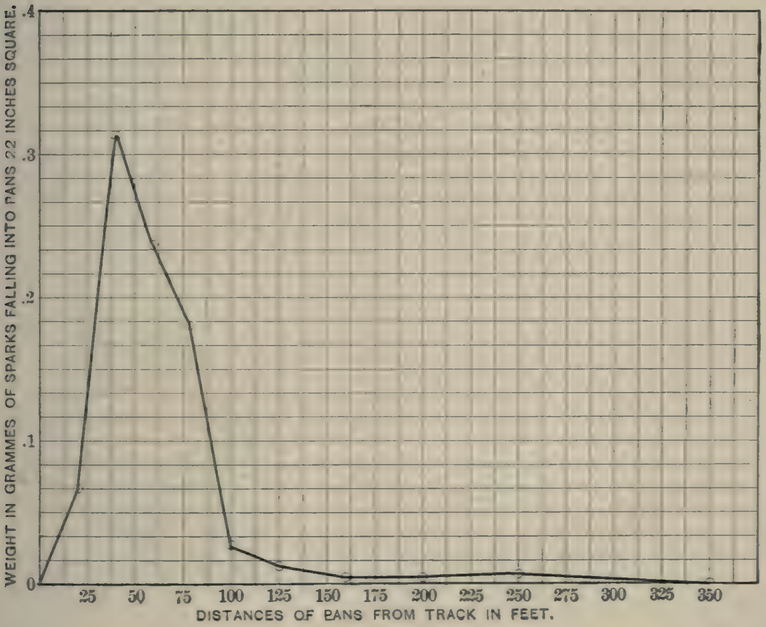


FIG. 58.

SPARK-LOSSES FROM LOCOMOTIVES ON THE ROAD.
TEST NO. 8.

The photograph for this test failed. The following is a summary of the conditions which prevailed:

Number of locomotives	1
Type of locomotive	Mogul
Number of freight-cars	12
Speed of train, miles per hour	21.6
Velocity of wind, miles per hour	7
Character of smoke	dark

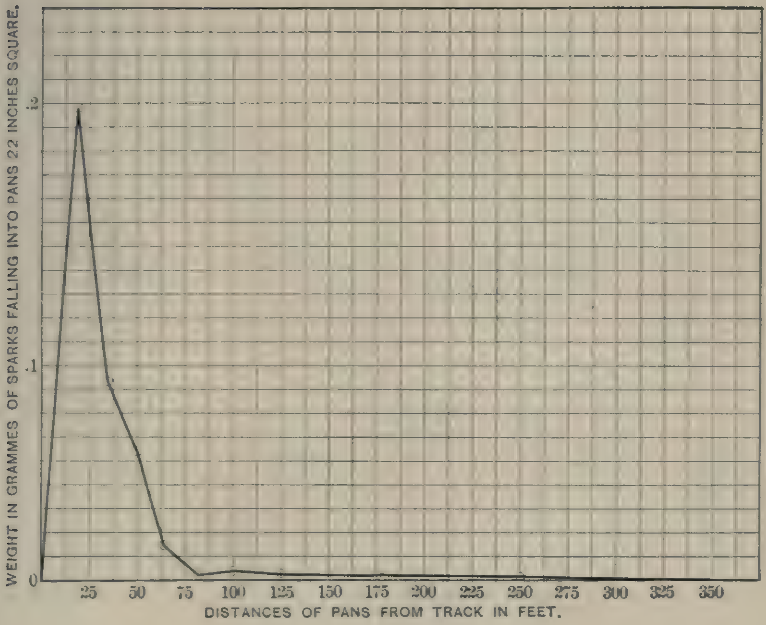


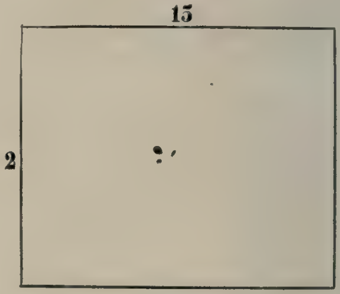
FIG. 59.

SPARKS FROM TEST NO. 2.

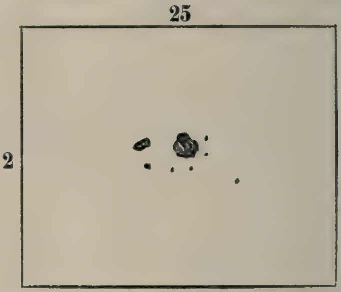
THIS test and Test No. 10, the results of which follow, are typical of those tests in which the heaviest fall of sparks is found at the greatest distance from the track. The spots within each rectangle show the number and actual size of sparks collected in each pan. The rectangle does not indicate the size of the pan, which was 22 inches square.

The sparks collected include those deposited by the locomotive at the head of the train (Fig. 49) and by the "pusher" at its rear.

Speed of train..................	15.7 miles per hour
Velocity of wind..............	11.6 miles per hour
Number of freight-cars........	29



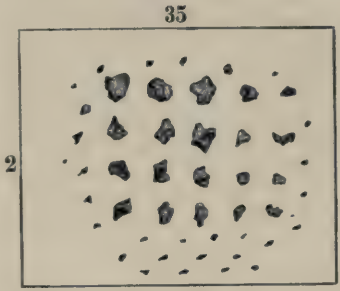
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *15 feet* from the centre of the track.



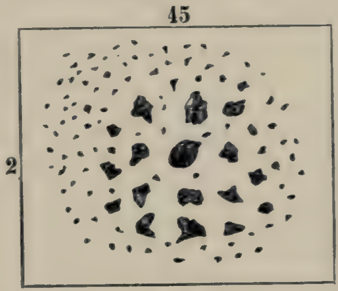
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *25 feet* from the centre of the track.

Sparks from Test No. 2.—*Continued.*

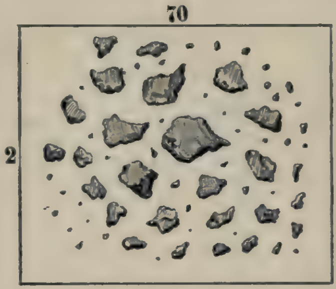
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *35 feet* from the centre of the track.



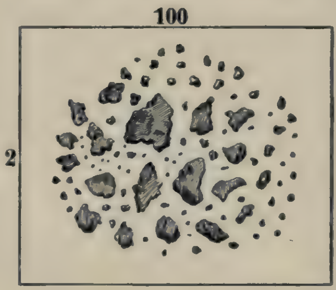
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *45 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *70 feet* from the centre of the track.

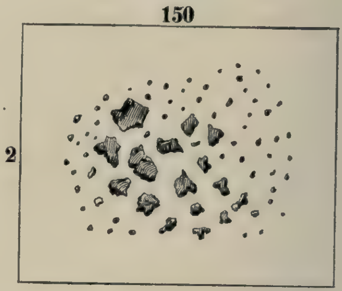


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *100 feet* from the centre of the track.

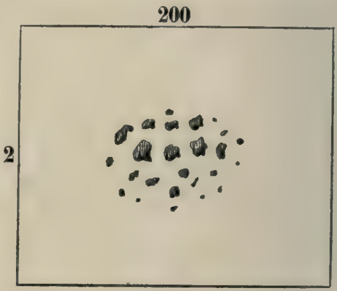


Sparks from Test No. 2.—*Continued.*

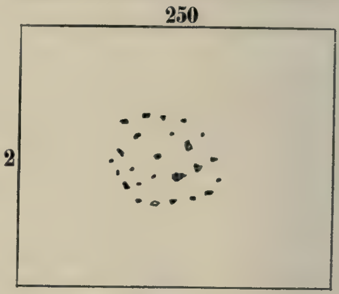
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *150 feet* from the centre of the track.



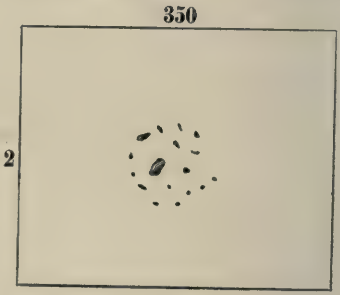
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *200 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *250 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches at a distance of *350 feet* from the centre of the track.



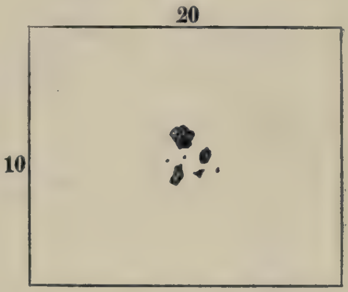
Sparks from Test No. 10.

THIS test and Test No. 2, the results of which are given on preceding pages, are typical of those tests in which the heaviest fall of sparks is found at the greatest distance from the track. The spots within each rectangle show the number and actual size of sparks collected in each pan. The rectangle does not indicate the size of the pan, which was 22 inches square.

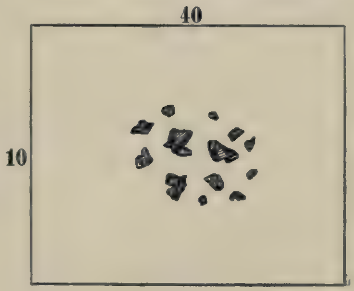
The sparks collected include those deposited by the locomotive at the head of the train (Fig. 51) and by the "pusher" at its rear.

Speed of train	14.9 miles per hour
Velocity of wind	7.9 miles per hour
Number of freight-cars	34

Actual size and number of sparks falling within an area of 484 square inches, at a distance of *20 feet* from the centre of the track.

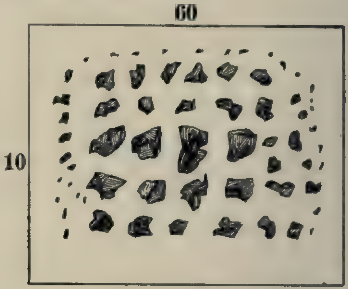


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *40 feet* from the centre of the track.

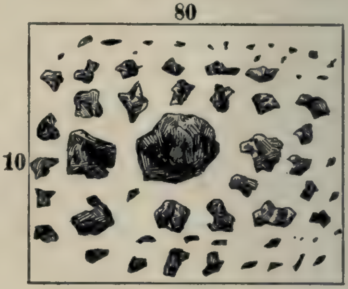


SPARKS FROM TEST NO. 10.—*Continued.*

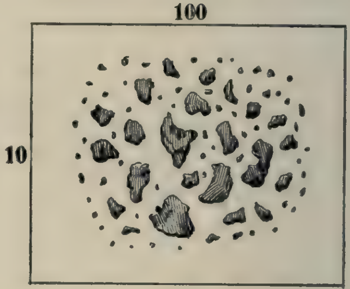
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *60 feet* from the centre of the track.



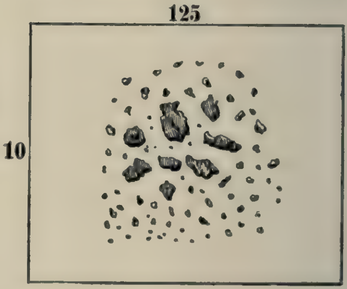
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *80 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *100 feet* from the centre of the track.

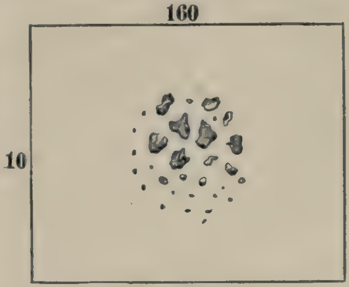


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *125 feet* from the centre of the track.

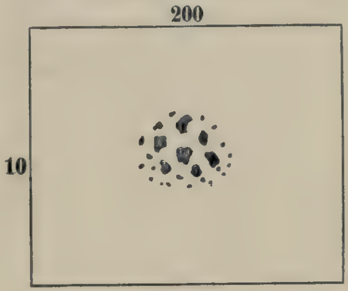


Sparks from Test No. 10.—*Continued.*

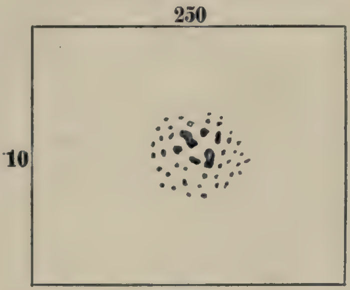
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *160 feet* from the centre of the track.



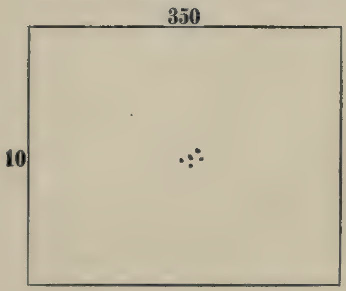
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *200 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *250 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *350 feet* from the centre of the track.



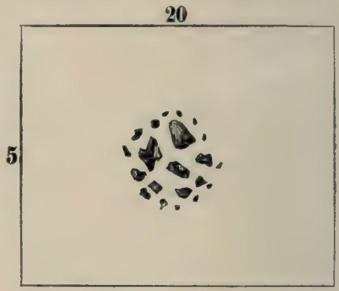
SPARKS FROM TEST NO. 5.

THIS test and Test No. 6, the results of which follow, are typical of those tests in which the heaviest fall of sparks is found at a moderate distance from the track. The spots within each rectangle show the number and actual size of sparks collected in each pan. The rectangle does not indicate the size of the pan, which was 22 inches square.

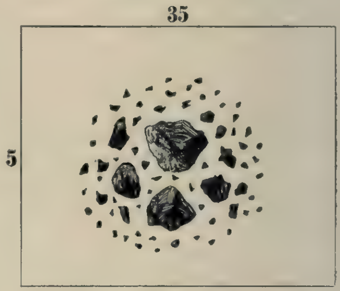
The sparks collected include those deposited by the locomotive at the head of the train (Fig. 53) and by the "pusher" at the rear.

Speed of train................	15.1 miles per hour
Velocity of wind.............	8.7 miles per hour
Number of freight-cars........	34

Actual size and number of sparks falling within an area of 484 square inches, at a distance of *20 feet* from the centre of the track.

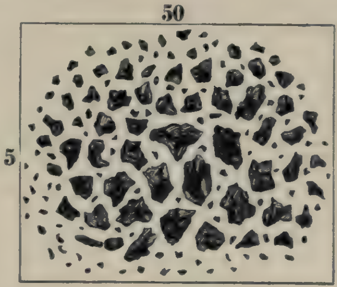


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *35 feet* from the centre of the track.

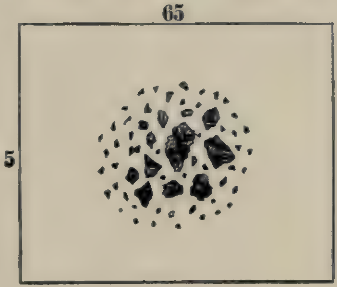


Sparks from Test No. 5.—*Continued.*

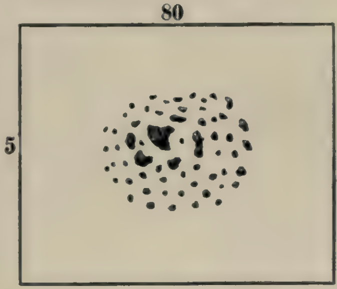
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *50 feet* from the centre of the track.



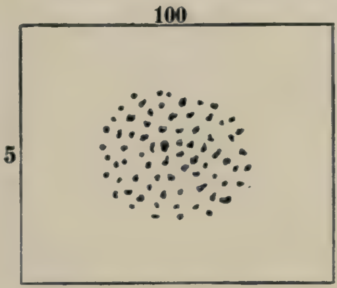
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *65 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *80 feet* from the centre of the track.

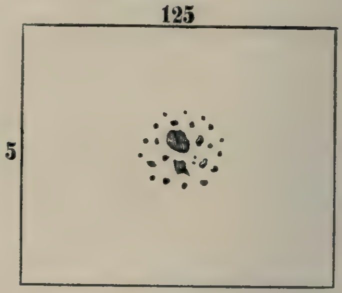


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *100 feet* from the centre of the track.

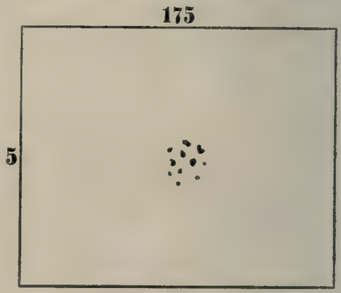


SPARKS FROM TEST NO. 5.—*Continued.*

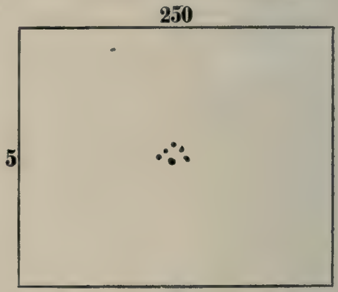
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *125 feet* from the centre of the track.



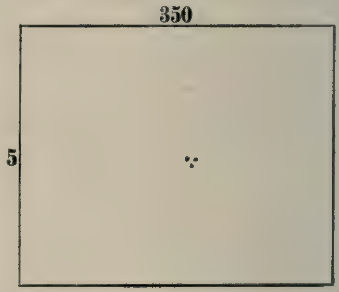
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *175 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *250 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *350 feet* from the centre of the track.



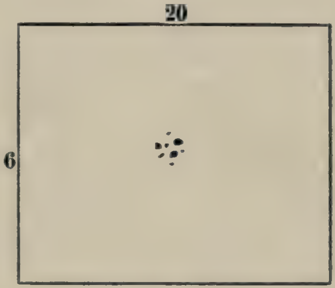
Sparks from Test No. 6.

THIS test and Test No. 5, the results of which are given on preceding pages, are typical of those tests in which the heaviest fall of sparks is found at a moderate distance from the track. The spots within each rectangle show the number and actual size of sparks collected in each pan. The rectangle does not indicate the size of the pan, which was 22 inches square.

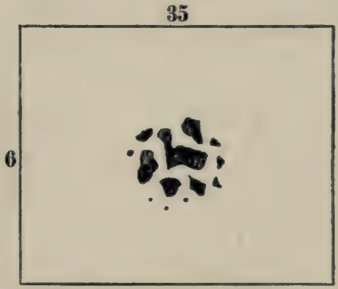
The sparks collected are those deposited by a single locomotive (Fig. 55) at the head of a train.

Speed of train................	23.3 miles per hour
Velocity of wind.............	9.8 miles per hour
Number of freight-cars........	11

Actual size and number of sparks falling within an area of 484 square inches, at a distance of *20 feet* from the centre of the track.

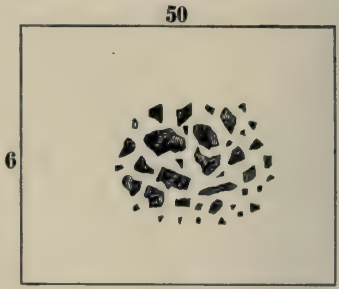


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *35 feet* from the centre of the track.

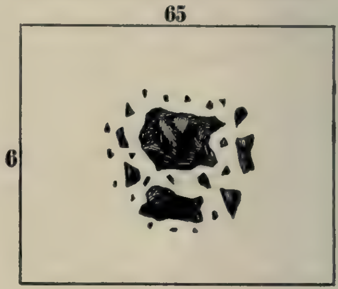


Sparks from Test No. 6.—*Continued.*

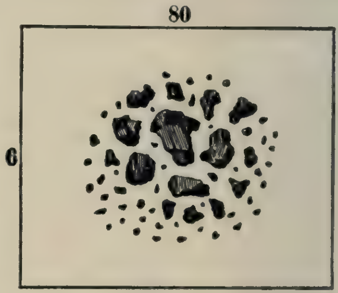
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *50 feet* from the centre of the track.



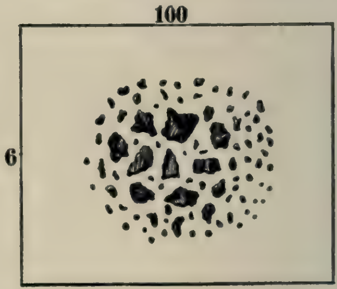
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *65 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *80 feet* from the centre of the track.

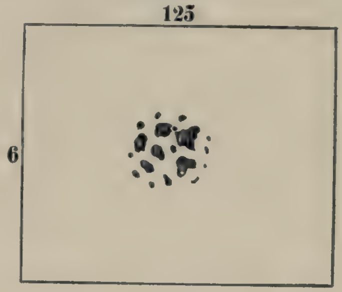


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *100 feet* from the centre of the track.

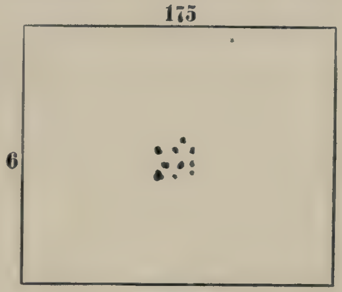


Sparks from Test No. 6.—*Continued.*

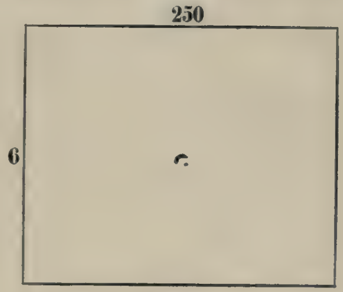
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *125 feet* from the centre of the track.



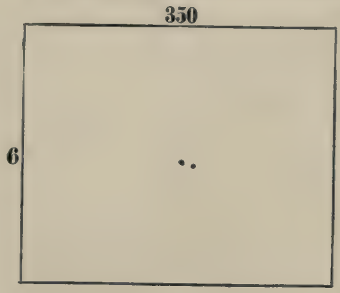
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *175 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *250 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *350 feet* from the centre of the track.

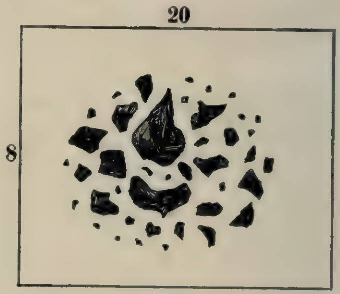


SPARKS FROM TEST NO. 8.

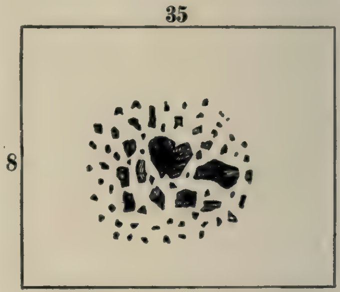
THIS test and Test No. 14, the results of which follow, are typical of those tests in which the heaviest fall of sparks is found near to the track. The spots within each rectangle show the number and actual size of sparks collected in each pan. The rectangle does not indicate the size of the pan, which was 22 inches square.

The sparks collected were from a single locomotive at the head of the train.

Speed of train	21.6 miles per hour
Velocity of wind	7 miles per hour
Number of freight-cars	12



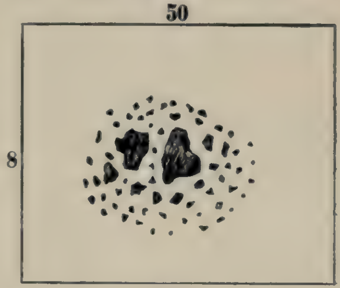
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *20 feet* from the centre of the track.



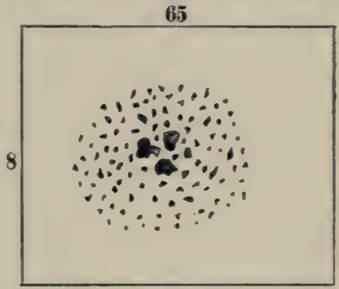
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *35 feet* from the centre of the track.

SPARKS FROM TEST NO. 8.—*Continued.*

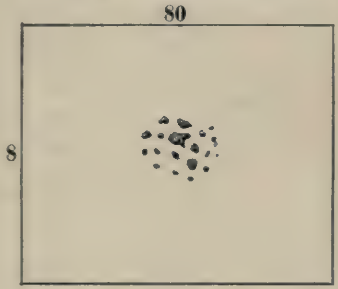
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *50 feet* from the centre of the track.



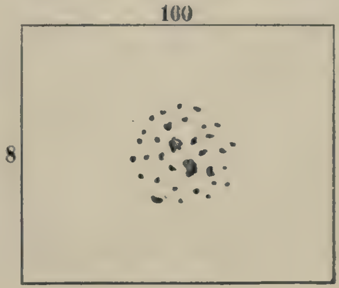
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *65 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *80 feet* from the centre of the track.

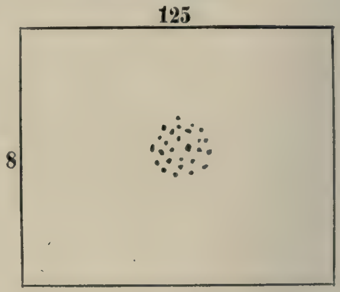


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *100 feet* from the centre of the track.

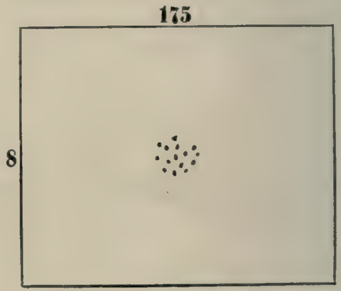


SPARKS FROM TEST NO. 8.—*Continued.*

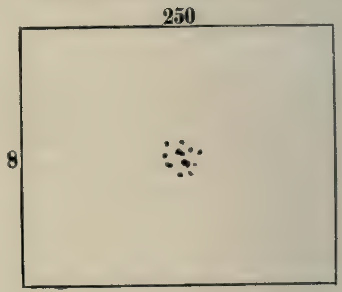
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *125 feet* from the centre of the track.



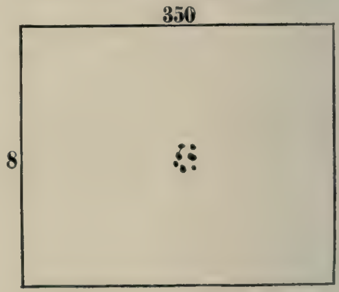
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *175 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *250 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *350 feet* from the centre of the track.

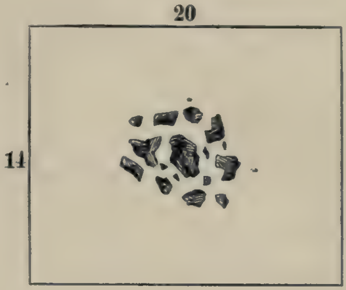


SPARKS FROM TEST NO. 14.

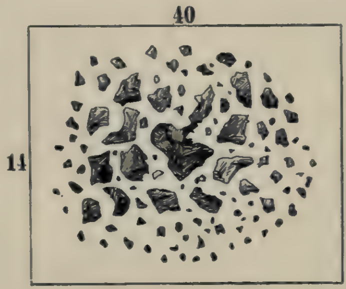
THIS test and Test No. 8, the results of which are given on preceding pages, are typical of those tests in which the heaviest fall of sparks is found near to the track. The spots within each rectangle show the number and actual size of sparks collected in each pan. The rectangle does not indicate the size of pan, which was 22 inches square.

The sparks collected include those deposited by the locomotive at the head of the train (Fig. 57) and by its "pusher" at the rear.

Speed of train................	18.3 miles per hour
Velocity of wind.............	8.9 miles per hour
Number of freight-cars........	30



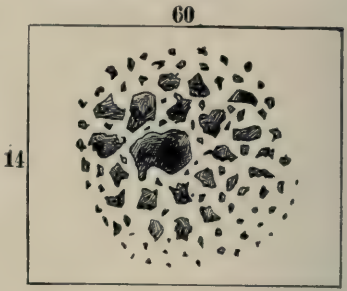
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *20 feet* from the centre of the track.



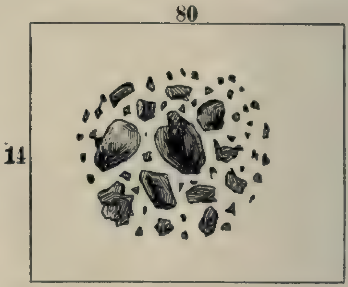
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *40 feet* from the centre of the track.

SPARKS FROM TEST NO. 14.—*Continued.*

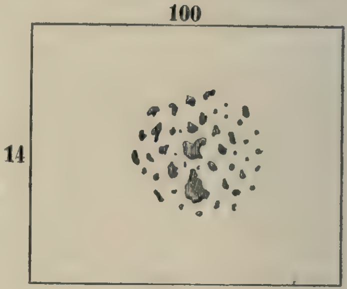
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *60 feet* from the centre of the track.



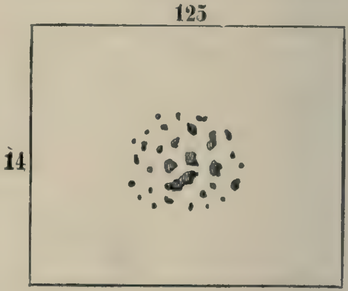
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *80 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *100 feet* from the centre of the track.

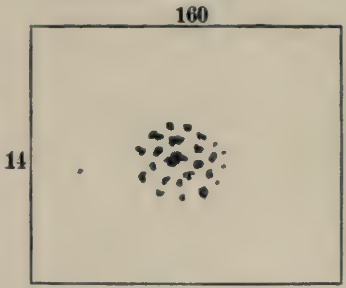


Actual size and number of sparks falling within an area of 484 square inches, at a distance of *125 feet* from the centre of the track.

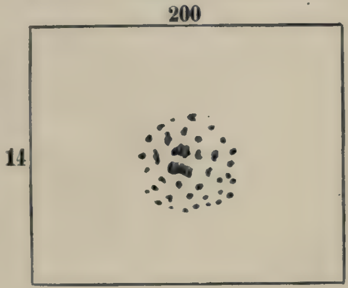


SPARKS FROM TEST NO. 14.—*Continued.*

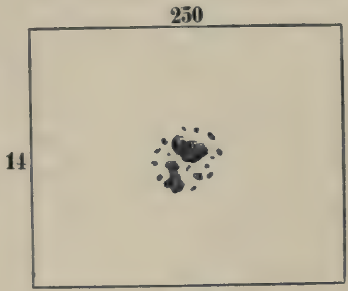
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *160 feet* from the centre of the track.



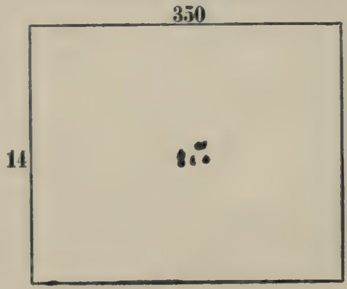
Actual size and number of sparks falling within an area of 484 square inches, at a distance of *200 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *250 feet* from the centre of the track.



Actual size and number of sparks falling within an area of 484 square inches, at a distance of *350 feet* from the centre of the track.



32. **A Summarized Statement of Results** of experiments to determine the spread of sparks along the right-of-way is as follows:

1. The greatest number of sparks fell at from 35 to 150 feet from the centre of the track. It may therefore be assumed, from the data at hand, that the possibility of fire is greatest within these limits.

2. With a few exceptions, the pans nearest the track, i.e., from 15 to 20 feet, caught but few sparks. Local conditions, due to air-currents about the train, may in part be responsible for this.

3. No scorching of the cotton in the pans was in any case observed. This may be accounted for by the fact that during the time the tests were run (in April and May) the temperatures were comparatively low. Some of the larger sparks were quite warm, however, when picked up immediately after falling.

4. Beyond 125 feet from the centre of the track the sparks were of such character as to preclude any possibility of fire from them.

5. In March, preceding the tests, when a light crust of snow covered the ground, it was possible to trace evidence of dust from passing locomotives at a distance of 800 feet from the track. The wind velocity was high—about 20 miles an hour. Nothing in this observation should be interpreted as in conflict with the statement of the preceding paragraph.

CHAPTER VII.

THEORETICAL CONSIDERATIONS AFFECTING THE SPREAD OF SPARKS BY MOVING LOCOMOTIVES.

33. THE results of actual observations upon the size of sparks, and the extent of area over which they are distributed by moving locomotives, have been presented in the preceding chapter. It is the purpose of the present chapter to discuss the various forces affecting the spread of sparks and to show their relation one to another, so that if certain conditions are assumed to prevail, the resulting effect can be predicted.

34. **Preliminary Conceptions.**—All change of motion is the result of force. If a body freed from the influence of all forces save that of gravity be thrown vertically upward, the action of gravity will cause it to return by the same path as that by which it rose until it rests upon the same spot from whence it started. Or, if a body in the air is freed from the influence of all forces excepting that of the wind, it will move with the wind in the direction in which the wind is moving and at the same velocity as the wind. The effect of several forces acting at the same time upon a given body was originally stated by Newton as follows: "When any number of forces act simultaneously upon a body, then whether the body be originally at rest or in motion, each force produces exactly the same effect in magnitude and direction as if acting alone." This principle is often called the Law of Independence of Motion. By this law it will be seen that if a body, as,

for example, a spark, be projected upwards in the presence of a strong wind, it will move upward in response to the initial impulse to a certain height and will then descend. This upward and downward movement will extend over the same vertical distances, and will take the same time as would be the case if the wind were not blowing. On the other hand, a spark thus projected will respond to the influence of the wind throughout the time it remains in the air to the same extent that it would if the force of gravitation were not in action. Being, therefore, under the influence of gravity, which tends to retard or to produce motion in vertical lines, and under the influence of the wind, which tends to produce motion in horizontal lines, the actual path followed will be a curve.

35. The Path and Horizontal Displacement of a Body Assumed to be in Air at a given Distance from the Ground and Free to Move Both in Response to Gravity and to the Influence of Wind Acting in a Horizontal Direction.—If, now, we assume a body, as A, Fig. 60, held in the air at a given distance from the ground and subject to the action of gravity and to the influence of wind, it will, when released, move in obedience to both of these forces; it will fall through the height h to the ground, and in the time occupied in falling the wind will have caused it to move horizontally through the distance d, the path followed by the body being described by the curve AB. From this general statement it is possible to express mathematically the relation between the height of the fall h and the horizontal displacement d, which is

$$d = v\sqrt{\frac{2h}{g}},$$

in which d is the horizontal distance traversed in feet; v, the velocity of wind in feet per second; h, the height through which the body is allowed to fall in response to gravity; and g, the acceleration due to gravity, or 32.2.* By use of this

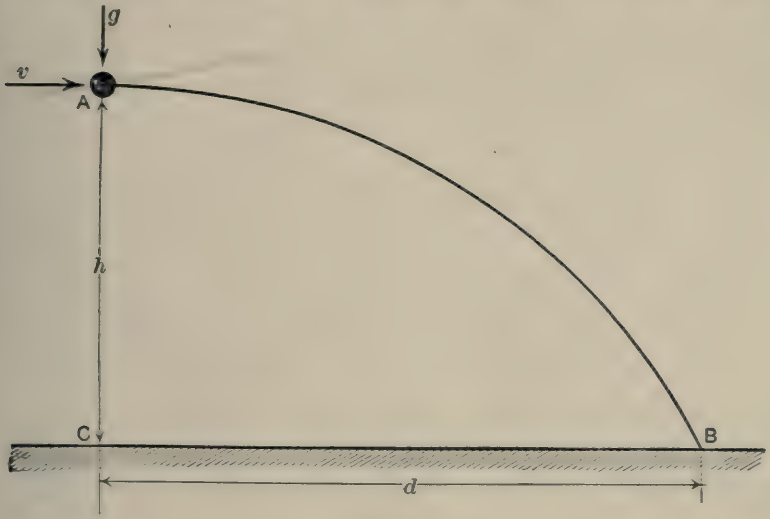


FIG. 60.

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* The full demonstration is as follows:

Let v = velocity of wind in feet per second;

h = initial height in feet which a freely falling body may be above the ground;

d = horizontal distance in feet through which the body would move in falling to the ground;

t = time of descent in seconds;

g = acceleration due to gravity (= 32.2 feet per second).

If the effect of the wind velocity alone is considered, then

$$d = vt, \qquad (1)$$

whence

$$t = \frac{d}{v}. \qquad (2)$$

If the effect of the acceleration of gravity alone is considered, then, from the law of falling bodies,

$$h = \tfrac{1}{2}gt^2, \qquad (3)$$

whence

$$t = \sqrt{\frac{2h}{g}}. \qquad (4)$$

But when the forces act simultaneously, the time t, required to fall the distance h, is the same as the time required to travel the distance d. Exformula the values for *d* shown by Table IX have been obtained. The table shows how far it is possible for a particle to be borne by the wind starting from points at various distances from the ground and influenced by wind of different velocities.

TABLE IX.

SHOWING THE HORIZONTAL DISPLACEMENT OF A BODY UNDER THE INFLUENCE OF WIND OF DIFFERENT VELOCITIES, WHILE FALLING FROM DIFFERENT HEIGHTS.

Velocity of Wind.		Initial Height in Feet from which the Body is Assumed to Start.							
Feet per Second.	Miles per Hour.	15	20	25	30	40	50	75	100
2.93	2	2.8	3.3	3.6	4.0	4.6	5.2	6.3	7.3
7.34	5	7.0	8.1	9.1	10.0	11.5	13.0	15.8	18.3
11.74	8	11.3	13.0	14.5	16.0	18.4	20.8	25.3	29.2
17.60	12	16.9	19.5	21.8	23.9	27.6	31.2	38.0	43.8
23.47	16	22.5	26.0	29.1	31.9	36.8	41.5	50.5	58.4
29.34	20	28.2	32.6	36.4	39.9	46.1	51.9	63.3	73.0
44.01	30	42.2	48.8	54.6	59.8	69.1	77.9	94.9	109.6
58.68	40	56.3	65.1	72.7	79.8	92.1	103.8	126.6	146.1
73.35	50	70.4	81.4	90.9	99.7	115.1	129.8	158.2	182.6
88.02	60	84.5	97.7	109.1	119.7	138.2	155.8	189.9	219.1

For example, when the initial height *h* of the body above the ground is 20 feet and the wind velocity is 12 miles per hour, the horizontal distance *d* is 19.5 feet. Again, when the initial height is 50 feet and the wind velocity is 40 miles per hour, the distance is 103.8 feet. It is to be noted that the

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pressing this fact mathematically by equating the right-hand members of (2) and (4), we get

$$\frac{d}{v} = \sqrt{\frac{2h}{g}}, \qquad (5)$$

whence

$$d = v\sqrt{\frac{2h}{g}}. \qquad (6)$$

equation and the table derived by its use, presuppose that the body in question is free from the action of all forces except that of gravity and that of the horizontal movement of the wind. Under this assumption the values given are absolute. As a matter of fact, a body in falling in air is retarded somewhat by the resistance of the atmosphere, and would therefore be a trifle longer in its descent than is allowed by the formula, with the result that the horizontal distance would also be greater. In another paragraph an attempt will be made to correct for this influence. For the present the results as given should be accepted as defining the physical relationship applicable to a freely falling body.

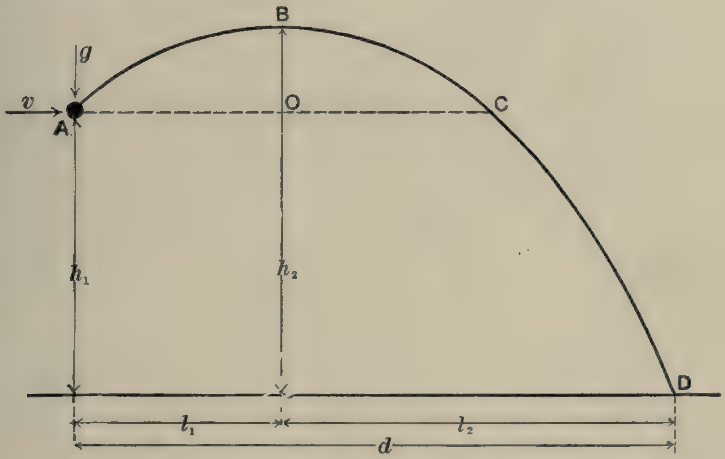

FIG. 61.

35. The Path and Horizontal Displacement of a Body Projected Vertically Upward when Free to Respond to the Influence of Gravity and of Wind Acting Horizontally.—

Fig. 61 is a graphical representation of the path followed by a freely falling body which when starting from a definite point, as *A*, is projected vertically upward while subject to the action of the wind under the influence of which it is assumed to move horizontally. The arrow g shows the direction of the force of gravity. The arrow v shows the direction of the constant wind velocity. The curved line $ABCD$ shows the path which the body will follow in its journey to the ground. The maximum height, h_2, is not reached until some distance, l_1, from the initial position. From this point the body gradually falls to the ground through a horizontal distance l_2. The total horizontal distance* traversed by the body is expressed by

$$d = v\left\{\sqrt{\frac{2h_2}{g}} + \sqrt{\frac{2(h_2 - h_1)}{g}}\right\}. \quad . \quad . \quad (b)$$

Table X gives values for d as obtained from formula (b) by the substitution of successive values of h_2 and v. The

---

* Let v_1 = velocity of wind in feet per second;
h_1 = initial height in feet of body above ground;
h_2 = maximum height in feet of body above ground;
g = acceleration of gravity (= 32.2 feet per second);
d = horizontal distance in feet through which the body would move in falling to the ground.

The path of the body is divided into two parts: that from A to B, and that from B to D.

The horizontal distance traversed in passing from A to B is expressed by

$$l_1 = v\sqrt{\frac{2(OB)}{g}} = v\sqrt{\frac{2(h_2 - h_1)}{g}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The horizontal distance traversed in passing from B to D is expressed by

$$l_2 = v\sqrt{\frac{2h_2}{g}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

But the total horizontal distance is $l_1 + l_2 = d$. Therefore

$$d = v\sqrt{\frac{2h_2}{g}} + v\sqrt{\frac{2(h_2 - h_1)}{g}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or

$$d = v\left\{\sqrt{\frac{2h_2}{g}} + \sqrt{\frac{2(h_2 - h_1)}{g}}\right\}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

initial height h_1 is taken at 15 feet.* For example, when the maximum height to which the body rises is 20 feet and the wind velocity is 12 miles per hour, the horizontal distance d through which the body will travel in falling to the ground is found to be 29.4 feet. If the maximum height be increased to 50 feet and the wind velocity to 40 miles per hour, the horizontal distance d is found to be 191.4; if the wind velocity be 60 miles, the displacement becomes 247.8 feet.

TABLE X.

SHOWING THE HORIZONTAL DISPLACEMENT OF A BODY PROJECTED VERTICALLY UPWARD FROM AN INITIAL HEIGHT OF FIFTEEN FEET AND FREE TO MOVE BOTH IN RESPONSE TO GRAVITY AND TO THE INFLUENCE OF WIND ACTING IN A HORIZONTAL DIRECTION.

Velocity of Wind.		Maximum Height in Feet to which Body is Projected.							
Feet per Second.	Miles per Hour.	15	20	25	30	40	50	75	100
2.93	2	2.8	4.9	5.9	6.8	8.3	9.6	12.0	14.1
7.34	5	7.0	12.2	14.8	17.0	20.7	23.9	30.0	35.2
11.74	8	11.3	19.6	23.7	27.3	33.0	38.3	48.0	56.2
17.60	12	16.9	29.4	35.6	40.9	49.6	57.4	71.9	84.4
23.47	16	22.5	39.2	47.5	54.6	66.1	76.5	95.1	112.5
29.34	20	28.2	50.0	59.4	68.2	82.6	95.7	119.9	140.6
44.01	30	42.2	73.5	89.1	102.3	123.9	143.5	179.9	210.9
58.68	40	56.3	98.0	118.7	136.4	165.2	191.3	239.8	281.2
73.35	50	70.4	122.5	148.4	170.5	206.5	239.1	299.8	351.5
88.02	60	84.5	147.0	178.1	204.6	247.8	286.9	359.7	421.9

While the results given in Tables IX and X are not without value as a basis from which to predict the probable flight of sparks, it should be remembered that the body in the preceding illustrations is assumed to fall freely, as in a vacuum, and when liberated to at once partake of the velocity of the wind. We are now to consider what are the modifications in the assumptions and results which will follow the substitution of a spark for a freely falling body.

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* An initial height of 15 feet represents approximately the distance of the top of a locomotive-stack above the ground.

37. The Horizontal Displacement of Sparks which are Assumed to be in Air Free to Respond to the Action of Gravity and to the Influence of Wind Acting Horizontally.—The theoretical considerations of the preceding paragraphs relative to the action of any freely falling body is applicable to a spark after leaving the stack of a locomotive. The values given in Tables IX and X do not, however, accurately represent the horizontal distances which a spark may be assumed to travel after leaving the stack, owing to the fact that these values were computed by using 32.2 as the acceleration due to gravity. This value represents the velocity of a body starting from rest and falling in vacuum for one second. A spark is a comparatively light body, and the resistance of the atmosphere impedes its movements; hence, after its emission from a locomotive stack, it will remain in the air for a longer time than a heavier or more dense body. In other words, the apparent value of the acceleration of gravity for a spark is less than 32.2 feet per second. Before tables can be constructed, similar in form to those representing the movement of a freely falling body (Tables IX and X), it is first necessary to determine the acceleration for a falling spark in air. Such a determination has been made experimentally. To serve in this research, special apparatus was designed, the essential details of which are shown in Fig. 62. It consists of three vertical rods, the two outer ones being placed before a graduated scale showing feet and inches. Upon each of these two outer rods slides a horizontal arm, at the outer end of which is fastened a cylindrical tube, open at both ends. Two movable horizontal arms extend from the central rod. At the extremities

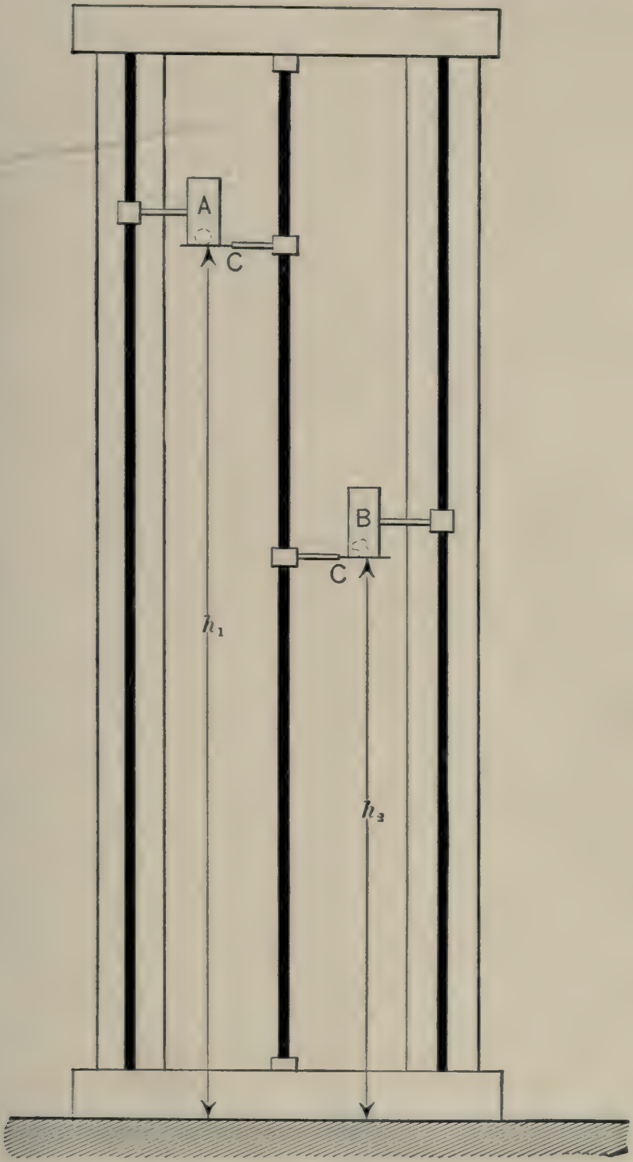

FIG. 62.

of each of these arms is fastened a flat piece of metal for covering the bottom of the tubes. In conducting the experiments the tube *A*, Fig. 62, was first placed at some predetermined height h_1, and the movable bottom *C* adjusted to the lower end of the tube. The tube *B* was then placed at some height less than h_1, and its bottom piece likewise adjusted. In the upper tube, *A*, was next placed a small lead bullet. In the lower tube, *B*, was placed a spark taken from the front-end of a locomotive. A quick rotation of the central rod served to withdraw the bottoms from both tubes simultaneously and to allow their contents, in one case a bullet, and in the other case a spark or cinder, to fall to the floor. By repeated trials the tube *B* was finally placed at a height such that the spark and bullet both reached the floor at the same instant. By noting the heights h_1 and h_2 from which the two bodies dropped, respectively, and from a knowledge of the acceleration of gravity for the bullet (assumed to be 32.2), the acceleration for the falling spark was determined.*

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* Let h_1 = height in feet of bullet above the floor;
h_2 = height in feet of spark above the floor;
t = time in seconds of descent for spark and bullet;
g = 32.2;
a = acceleration for spark.

Then, from the law of falling bodies:
For the bullet

$$h_1 = \tfrac{1}{2}gt^2, \qquad (1)$$

whence

$$t^2 = \frac{2h_1}{g}. \qquad (2)$$

For the spark

$$h_2 = \tfrac{1}{2}at^2, \qquad (3)$$

whence

$$t^2 = \frac{2h_2}{a}. \qquad (4)$$

But the time of descent, t, is the same for the bullet as for the spark.

A long series of experiments was thus conducted, and from the results obtained the average value of the acceleration for a falling spark was found to be 22.72. The sparks experimented with were both cold and incandescent, but differences due to changes in the temperature of the spark were too small to be detected.

Tables XI and XII have been computed under conditions identical with Tables IX and X, respectively, except that the value of a (22.72) was used instead of g (32.2). It is to be noted that the values of d given in Tables XI and XII are uniformly greater than those given in Tables IX and X, respectively, a fact entirely consistent with the conditions imposed.

38. The Effect of the Direction of the Wind on the Distance from the Track to which Sparks may be Carried.—It is obvious that a spark projected from a moving locomotive will, other things being equal, travel a maximum distance from the track when the direction of the wind is at right angles to the direction of the track. The values given in the preceding tables may be taken to represent maximum distances from the track at which sparks will alight when the direction of the wind is at right angles to the track. For all other directions of wind relative to track, the distances from the track at which sparks will find lodgment will be less than those given in the tables. The diagram Fig. 63 will serve to make these state-

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Expressing this mathematically by equating the right-hand members of (2) and (4),

$$\frac{2h_1}{g} = \frac{2h_2}{a}. \qquad (5)$$

Therefore

$$a = \frac{h_2}{h_1}g. \qquad (6)$$

TABLE XI.

SHOWING THE HORIZONTAL DISPLACEMENT OF A SPARK UNDER THE INFLUENCE OF WIND OF DIFFERENT VELOCITIES, WHILE FALLING FROM DIFFERENT HEIGHTS.

Velocity of Wind.		Initial Height of Spark in Feet.							
Feet per Second.	Miles per Hour.	15	20	25	30	40	50	75	100
2.93	2	3.3	3.8	4.2	4.6	5.4	6.0	7.4	8.5
7.34	5	8.2	9.5	10.6	11.6	13.4	15.1	18.4	21.3
11.74	8	13.1	15.2	16.9	18.6	21.4	24.2	29.5	34.0
17.60	12	19.7	22.7	25.4	27.9	32.2	36.3	44.2	51.0
23.47	16	26.2	30.3	33.9	37.1	42.9	48.3	58.9	68.0
29.34	20	32.8	37.9	42.3	46.4	53.6	60.4	73.7	85.0
44.01	30	49.2	56.8	63.5	69.6	80.4	90.6	110.5	127.5
58.68	40	65.6	75.8	84.7	92.9	107.2	120.9	147.4	170.0
73.35	50	81.9	94.7	105.8	116.1	134.0	151.1	184.2	212.5
88.02	60	98.3	113.7	127.7	139.3	160.8	181.3	221.0	255.0

TABLE XII.

SHOWING THE HORIZONTAL DISPLACEMENT OF A SPARK PROJECTED VERTICALLY UPWARD FROM AN INITIAL HEIGHT OF FIFTEEN FEET AND FREE TO MOVE BOTH IN RESPONSE TO GRAVITY AND TO THE INFLUENCE OF WIND ACTING IN A HORIZONTAL DIRECTION.

Velocity of Wind.		Maximum Height in Feet to which the Spark is Projected.							
Feet per Second.	Miles per Hour.	15	20	25	30	40	50	75	100
2.93	2	3.3	5.7	6.9	7.8	9.6	11.1	13.9	16.4
7.34	5	8.2	14.3	17.3	19.8	24.0	27.8	34.9	40.9
11.74	8	13.1	22.8	27.6	31.8	38.5	44.5	55.8	65.5
17.60	12	19.7	34.2	41.5	47.6	57.7	66.8	83.7	98.2
23.47	16	26.2	45.6	55.3	63.5	76.9	89.1	111.7	130.9
29.34	20	32.8	57.0	69.1	79.4	96.1	111.3	139.6	163.7
44.01	30	49.2	85.5	103.7	119.2	144.2	167.0	209.4	245.5
58.68	40	65.5	114.0	138.2	158.8	192.3	222.7	279.1	327.4
73.35	50	81.9	142.5	172.8	198.5	240.4	278.3	348.9	409.2
88.02	60	98.3	171.1	207.3	238.1	288.4	334.0	418.7	491.0

ments clear. Table XIII gives multipliers by the use of which the values in Tables IX to XII, inclusive, can be made to show the distance from the centre of the track at which a spark will alight under the influence of winds which blow at various angles with the direction of the train's motion.*

TABLE XIII.

Angle ϕ, Fig. 63, which Direction of Wind makes with Direction of the Train's Motion.	Multipliers to be Used.
30	.500
45	.707
60	.866

For example, from Table XI it will be found that when the initial height is 20 feet and the wind velocity is 12 miles per hour, the maximum distance traversed by the spark will be 22.7 feet. This distance assumes the wind to blow at right angles with the track. If the wind is assumed to blow at an angle of 45° with the track, this value of *d* would become $.707 \times 22.734 = 16.0$. In a similar manner corrections may be applied to all the tables.

39. Effect of Train's Motion on the Distance from the Centre of the Track at which Sparks Find Lodgment.— The train's motion does not affect the maximum distance from the centre of the track at which the spark will alight except in so far as incidental air-currents may have their influence. The present purpose deals with the well-known physical conditions only. The ejected spark has the same forward motion

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* The distance AB (Fig. 63) traversed by the spark is the same whatever may be the direction of the wind. The distance CB varies with the angle ϕ, or

$$CB = (AB) \sin \phi. \quad \ldots\ldots\ldots \quad (1)$$

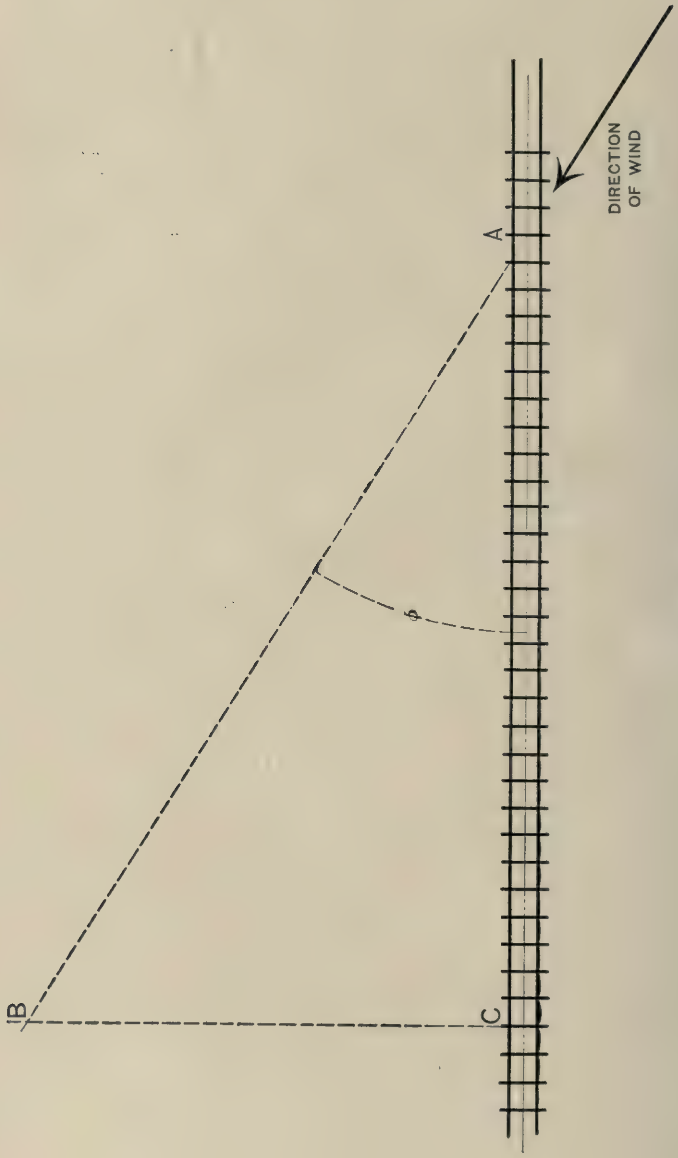

Fig. 63.

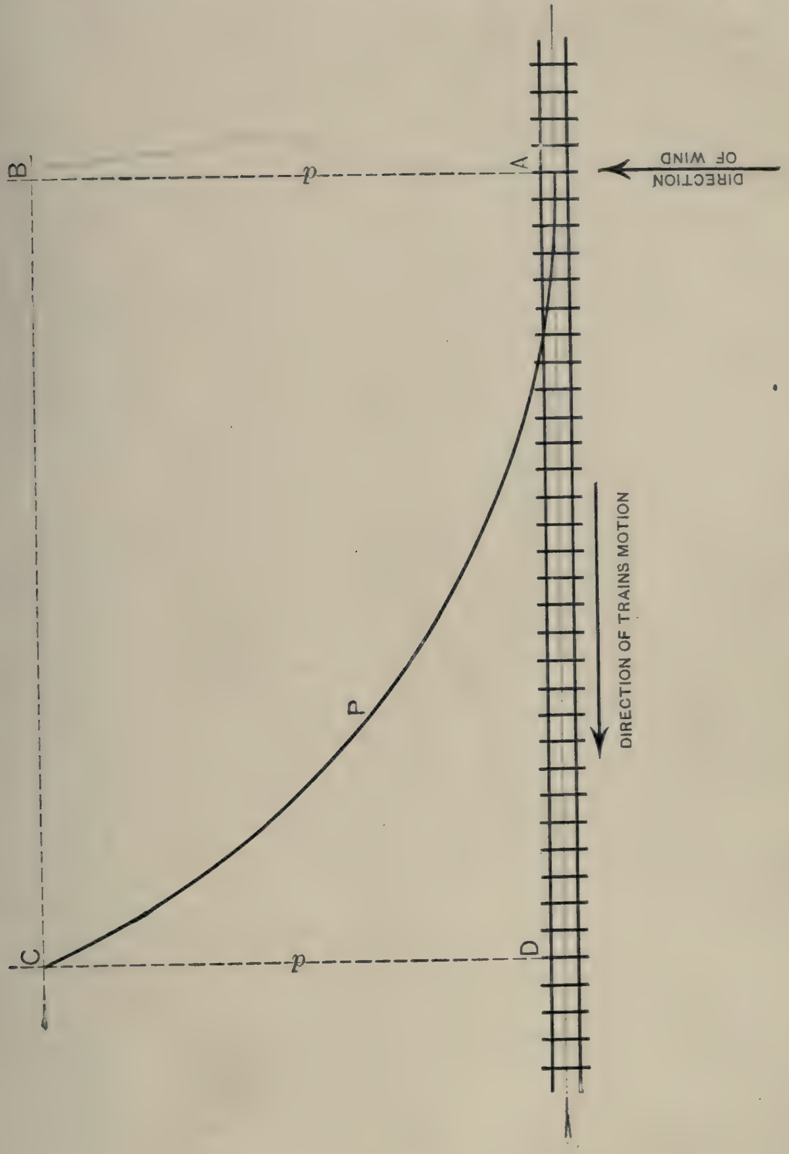

Fig. 64.

at the time it is sent forth from the stack as the locomotive itself, and it retains something of this motion until the initial energy is entirely absorbed by frictional contact with the atmosphere. That such motion does not affect the distance from the centre of the track traversed by the spark will appear from Fig. 64, which shows that if the locomotive were at rest, with the wind blowing across the track, the spark leaving *A* would follow the path *d* and land at a point *B*. If the locomotive were in motion, the spark starting from *A* would follow a curved path, landing at *C*. The distance *CB* depends upon the velocity of the train, but in either case the distances *AB* and *DC* depend upon the velocity of the wind and are equal.

CHAPTER VIII.

CHANCES OF FIRE FROM SPARKS.

40. A Review of Certain Facts already Presented.—In the preceding chapters there has been disclosed much that is important concerning the chances of fire from locomotive sparks. In a review of this matter it is well, first of all, to note that the production of sparks constitutes one of the necessary manifestations attending the action of a modern locomotive. It is not possible under any circumstances to entirely suppress them. Other things remaining the same, the amount of solid matter thrown from the stack increases when the intensity of the draft-action is increased, so that when the locomotive is worked to high power more sparks are thrown than when the power developed is low. Their volume varies, also, with the character of fuel; for example, anthracite coal gives off but few sparks, and these are composed chiefly of ash, while the light and friable lignite coals, such as must be used on many Western roads, are prolific spark-producers.

The composition of sparks varies from that of ash such as results from the complete combustion of fuel to that of fuel but slightly charred. Ash-sparks are incapable of carrying fire, but sparks composed of partially burned fuel may appear as small coals of coke which glow in the dark, or as incandescent or even as flaming particles. It is noteworthy that incandescent or flaming sparks constitute but a small proportion of all the solid matter ejected. It appears, also, that those particles which are composed of combustible material and which are, therefore, capable of carrying fire are, except in rare instances, deprived of fire by violent contact with the mechanism of the front-end against which they are driven, and by gathering moisture from the stream of exhaust-steam which serves to send them out into the atmosphere. In the vernacular of the road, they are "killed."

The size of sparks, as estimated from appearances about the stack, is often deceptive. Incandescent particles emitted, especially at night, appear large, when in reality they are very small. An investigation of the front-end mechanism, through which all sparks must pass before they can reach the outer air, will generally show that it is impossible for sparks larger than a half-kernel of corn to be emitted. An examination of sparks which perchance collect in quiet corners about railroad stations will supply added evidence tending to confirm this statement; the largest spark that can be found generally being much smaller than a half-kernel of corn.

The fact has been mentioned that but few of all the sparks delivered carry fire, and many of these are doubtless small in size. The experiments in gathering sparks from passing locomotives, the results of which are recorded in a preceding chapter, failed to disclose a single instance in which a falling spark sufficed to scorch common, unbleached cotton muslin which was laid in the bottom of the collecting-pans to receive them. These observations were made in the months of April and May. It is the testimony of many experienced railway men that atmospheric conditions have much to do with the fire-carrying properties of sparks; that in winter, when the air and all combustible material upon which sparks may fall are cold, fires from sparks never occur; that it is only in midsummer, when the temperature of the atmosphere is high, and when long-continued dry weather has prepared the grass of the roadside for a fire, and a hot sun has warmed it to a high temperature, that fires from sparks are, under normal conditions, possible. So small is the heat-carrying power of a spark from a locomotive in good order that it may be doubted whether such a spark was ever the means of communicating fire to the roof of a building, even when under the influence of a summer sun the roof had become well dried and highly heated, except in cases where it may have fallen on materials more finely divided than shingles.

The distance traversed by sparks, as shown by observations along the track, establishes the danger-line very close to the track. Both a large percentage of all sparks thrown out and the largest individual specimens were found, in the experiments herein recorded, within a distance of 100 feet from the centre of the track. This distance fixes the danger-line. As tending to further confirm this statement, the testimony of those who have had occasion to observe the progress of fires originating from locomotives is to the effect that while objects located at considerable distances from the track sometimes burn, the firing of such objects is not the immediate result of a spark from a locomotive; that the initial fire from the locomotive spark is invariably started upon the right-of-way inside of the fence; that this initial fire, which is invariably in the grass, is communicated to a pile of ties or of refuse materials or to the right-of-way fence, the burning embers of which are windborne to more distant objects. The fact, therefore, that a building 60 or 80 yards from the track may burn should not be accepted as evidence that sparks from a locomotive will carry fire to such distances, though a spark may have been an indirect cause of the fire. In all such cases, however, there will be evidence of the initial fire.

Against the statements of the preceding paragraphs may be urged the fact that persons standing at considerable distances from the track sometimes feel upon their face and hands the impact of particles discharged from a passing locomotive, the experience indicating that such particles do travel considerable distances. A close inspection of the particles which thus impress themselves will, however, show them to be very minute, so small in fact as to be hardly more than finely divided dust, wholly incapable of carrying fire. The hands and face are so very sensitive that the impress of such material gives one the impression of being bombarded by fragments of considerable size, but the slightest examination will suffice to convince him of his mistake. Obviously, the present discussion is not concerned with the distribution of these dust-like sparks.

Finally, as tending to still further confirm the conclusions already stated, it appears that if, in his efforts to make sparks travel long distances from the track, one abandons all consideration of local conditions, and bases an estimate on the physical laws governing the movement of all bodies in air, he will be obliged to assume that sparks rise to a very great height, or that they are influenced by a very strong wind, before his results will carry the sparks very far afield. In other words, it may be readily shown by the application of well-known laws applying to falling bodies that sparks sufficiently large to carry fire must, under ordinary conditions of discharge and of wind velocity, strike the ground within comparatively short distances from the track. A concise statement of the facts in this case is presented elsewhere.

41. The Influence of Air-currents about a Moving Train.—A moving train is surrounded by a zone of air which partakes more or less completely of the motion of the train itself, depending upon the thickness of the enveloping film which one chooses to consider, and upon the part of the train to which it is assumed to apply. The head of the moving train entering undisturbed air creates strong lines of pressure which wrap themselves in wave-like form about its initial end and are carried along by it. At the rear of the moving train the atmospheric pressure is less than normal, and the air rushes in from all sides in strong currents to fill the space left by the receding train. The effect of eddies thus formed upon the course of sparks discharged by the locomotive at the head of the train is a subject which probably has not been carefully studied. There is, however, much to sustain the theory that such sparks do not escape the influence of the eddies, that they are caught up by them, held within their influence, and finally drawn into the zone of low pressure at the rear of the train. In so far as this argument applies it serves to show that sparks which would otherwise be carried by the wind at right angles to the track are in reality carried along with the strong currents of air which move with the train until they settle upon the track at its rear.

An observer at the rear of a rapidly moving train cannot but be impressed by the vigor of the air-currents which are drawn in upon the track in its rear, reaching out to and influencing the motion of objects far distant from the track itself. The smoke from a locomotive at the head of a rapidly moving train trails close on the top of the train and drops as it passes over the last car, regardless of the direction or velocity of the wind.

Professor Francis E. Nipher, who has conducted elaborate experiments in determining the velocity of air-currents immediately about a moving train, argues that the effect of a moving train upon the atmosphere is such as to draw objects in its vicinity to itself. Hats which are blown from the heads of persons standing on a station platform are drawn under the train. Bed-mattresses rolled into bundles and piled upon the platform of a freight station have been observed to topple over under the influence of the wind from a passing train, and to be drawn under the wheels.* These considerations imply that sparks are not always free to respond to the influences of the wind, but that they are constrained in their motion, and that the effect of the resistance is to hold them to the course of the train.

42. Sparks from a Locomotive and Sparks from a Fixed Fire are not Subjected to the Same Influences.—It is a matter of common knowledge that sparks and sometimes brands arising from a fixed fire are carried by the wind over long distances. Fragments arising from a burning building, for example, are not infrequently carried a half mile or more. The question at once suggests itself as to why it is that brands from a burning building will travel such distances, while sparks from a locomotive are borne but a few feet. The answer is to be found in the different conditions which prevail in the two cases. Thus the shape of many of the fragments arising from a burning building well fits them for sailing in the air. When such a fragment, as, for example, a shingle, is blazing, it carries with it its own sustaining power. The heat from the flame stimulates ascending currents of air which, acting upon the broad surface of the fragment, tend to keep it in air while the wind bears it away. Again, a fixed fire serves to establish strong and far-reaching air-currents. If the wind is light, the column of heated air rises as the fire proceeds to greater and greater heights, the activity of the upward current becomes intensely strong, and particles which are caught within its influence are borne to very great heights. When these are of the sort which have been described, they settle very slowly after being released from the influence of the upward current, and drift away with the wind. If a large fixed fire occurs in the presence of a strong wind, the heated current constitutes a vast lane moving obliquely upward, reaching out over territory miles distant from the source of heat, bearing fragments and burning brands. In either case the power of the fixed fire in spreading sparks and brands lies in the fact that the heat developed in any one moment is supplemented by that which is developed the next moment. The currents of air which are set in motion by the heat developed during any one period are accelerated by the heat of a later period. The whole process is cumulative, and, other things being the same, the larger the fire the more rapid the currents become and the farther they extend their influence.

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* Professor Nipher's discussion and mathematical deductions concerning "The Frictional Effect of Railway Trains upon the Air" will be found in the Transactions of the Academy of Science of St. Louis, vol. x, No. 10, issued Nov. 12, 1900.

In striking contrast with all this are the conditions which surround the discharge from the stack of a locomotive. The sparks delivered are comparatively heavy in proportion to the extent of their exposed surface, and are thus not easily borne by ascending air-currents. They are so small that, while they give up the heat they carry very rapidly, the amount liberated is insufficient to stimulate to any marked degree upward currents of air about them. Again, the total amount of heat liberated from a locomotive is small compared with that generated by a burning building and, hence, all effects are less pronounced. As sparks go out of the locomotive stack, they find no far-reaching current to carry them on, for each exhaust from the stack is into undisturbed air. There is absolutely no cumulative effect. The heat-energy delivered is dissipated in the atmosphere which canopies the whole length of track, the discharge of a single minute being perhaps distributed over a mile of territory. There is, therefore, nothing to buoy up the locomotive spark but the initial velocity with which it is projected. From these considerations it should be evident that conclusions based on observations in connection with fixed fires are not applicable to the conditions affecting sparks in locomotive service.

APPENDIX.

THE PURDUE UNIVERSITY LOCOMOTIVE TESTING-PLANT.

43. Development of the Plant.—The discussions of the preceding chapters so frequently refer to results which have been obtained in connection with the experimental locomotive of Purdue University that it appears desirable that there be added some description of this locomotive and of the mechanism upon which it runs.

The purpose of the experimental testing-plant is to permit the action of a locomotive to be studied with the same ease and degree of accuracy as attends the study of a stationary engine. This is accomplished by converting, in effect, the locomotive into a stationary engine, but by doing this in such a manner that the locomotive remains free to exercise all its usual functions. The experimental locomotive is a machine which in size and in the completeness of its appointments is capable of doing immediate service on the road at the head of a train.

The plan of mounting a locomotive for experimental purposes as developed at Purdue involves (1) supporting wheels carried by shafts running in fixed bearings, to receive the locomotive drivers and to turn with them; (2) brakes mounted on the shafts of the supporting wheels, which should have sufficient capacity to absorb continuously the maximum power of the locomotive; (3) a traction dynamometer to measure the horizontal moving force of the engine on the supporting wheels.

Assume an engine, thus mounted, to be running in forward motion, the supporting wheels, the faces of which constitute the track, revolving freely in rolling contact with the drivers. The locomotive as a whole being at rest, the track under it (the tops of the supporting wheels) is forced to move backward. If now the supporting wheels be retarded in their motion, as, for example, by the action of friction-brakes, the engine must, as a result, tend to move off them. If they be stopped, the drivers must stop or slip. Whether the resistance be great or small, the force which is transmitted from the driver to the supporting wheel to overcome the resistance will reappear as a stress in the draw-bar, which alone holds the locomotive to its place upon the supporting wheels. The dynamometer constitutes the fixed point with which the draw-bar connects and serves to measure stresses transmitted.

It is evident from these considerations that the tractive power of such a locomotive may be increased or diminished by simply varying the resistance against which the supporting wheels turn, and that the readings of the traction dynamometer will always serve as a basis for calculating work done at the draw-bar. A locomotive thus mounted can be run either ahead or aback under any desired load and at any speed; and, while thus run, its performance can be determined with a degree of accuracy and completeness far excelling that which it is possible to secure under ordinary conditions on the road.

The matter of having a locomotive mounted upon the plan described was discussed at Purdue early in the year 1890, and it was so well received that in May, 1891, an order was given the Schenectady Locomotive Works for a 17″ × 24″ eight-wheeled engine. The details of the mounting were worked out during the two months following. In September the locomotive had been delivered, and it was in operation before the close of the year.

This plant, the first of its kind, is described in detail in a paper entitled "An Experimental Locomotive," which was read before the American Society of Mechanical Engineers at the San Francisco meeting in May, 1892.

On the 23d of January, 1894, the plant was destroyed by fire. Plans for reconstruction were at once entered upon and vigorously pushed. The damaged engine was extricated from the ruins of the building and repaired. The mounting machinery was redesigned, improved in details, and a separate building was built for its accommodation. It is this reconstructed plant (Figs. 65 to 69) which has served in all work the results of which are referred to in preceding chapters. Recently the original locomotive, now known as Schenectady No. 1, has given way to one of heavier and more modern design, but the later machine (Schenectady No. 2) is not associated with any of the results which are herein described.

A detailed description of the present plant is next presented:

44. **The Wheel-foundation.**—By reference to Figs. 65 and 66 it will be seen that there is provided a wheel-foundation, *A*, of nearly 25 feet in length. This is more than sufficient to include the driving-wheel base of any standard eight-, ten-, or twelve-wheeled engine. For engines having six wheels coupled, a third supporting axle will be added to those shown, and for engines having eight wheels coupled four new axles, having wheels of smaller diameter than those shown, will be used.

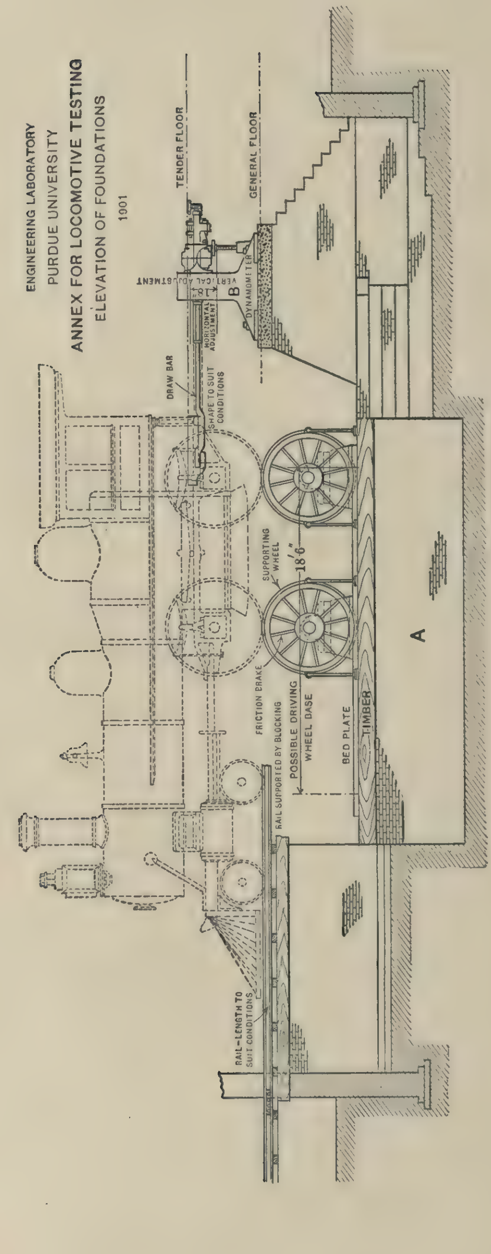
ENGINEERING LABORATORY
PURDUE UNIVERSITY
ANNEX FOR LOCOMOTIVE TESTING
ELEVATION OF FOUNDATIONS
1901
TENDER FLOOR
GENERAL FLOOR
VERTICAL ADJUSTMENT
18"
B
DYNAMOMETER
HORIZONTAL ADJUSTMENT
DRAW BAR
SHAPE TO SUIT CONDITIONS
SUPPORTING WHEEL
18'6"
FRICTION BRAKE
POSSIBLE DRIVING WHEEL BASE
BED PLATE
TIMBER
A
RAIL SUPPORTED BY BLOCKING
RAIL-LENGTH TO SUIT CONDITIONS

FIG. 65.

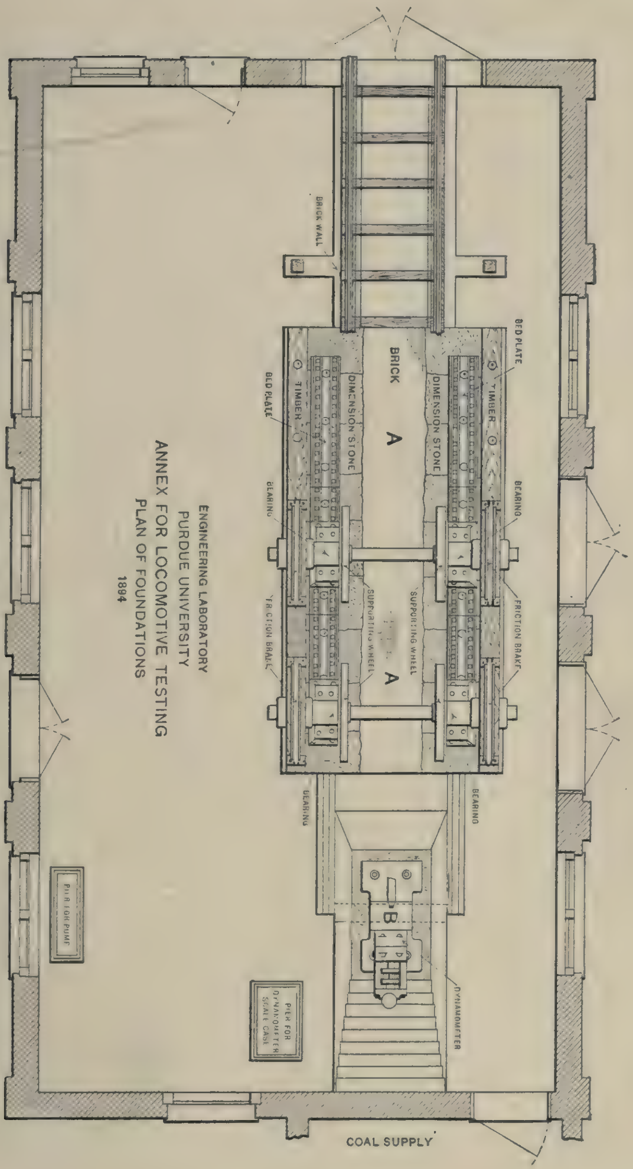
ENGINEERING LABORATORY
PURDUE UNIVERSITY
ANNEX FOR LOCOMOTIVE TESTING
PLAN OF FOUNDATIONS
1894
BRICK WALL
BED PLATE
BED PLATE
BRICK
A
A
DIMENSION STONE
DIMENSION STONE
TIMBER
TIMBER
BEARING
BEARING
FRICTION BRAKE
FRICTION BRAKE
SUPPORTING WHEEL
SUPPORTING WHEEL
BEARING
BEARING
B
DYNAMOMETER
PIER FOR PUMP
PIER FOR DYNAMOMETER SCALE CASE
COAL SUPPLY

FIG. 66.

The wheel-foundation carries cast-iron bed-plates, to which are secured pedestals for the support of the axle-boxes. The lower flanges of the pedestals are slotted and the bed-plates have threaded holes spaced along their length. By these means the pedestals may be adjusted to any position along the length of the foundation.

The boxes in use at present are plain babbitted shaft-bearings, and between each bearing and its pedestal a wooden cushion is inserted. A bearing has been designed for use in some special experiments which provides for the suspension of the axle from springs, but this bearing has not yet been used.

The outer edges of the wheel-foundation are topped by timbers to which the brake-cases are anchored. The brakes which absorb the power of the engine are the ones which were used in the original plant. They are constructed upon a principle developed by Professor Geo. I. Alden, and their capacity and wearing qualities are beyond question. The load upon them is controlled by varying the pressure of water which circulates through them and carries away the heat. The water-pressure acts upon stationary copper plates which are forced against a moving cast-iron disc, thereby producing friction. No provision is made for determining the load upon each brake, but the loads may be equalized by equalizing the flow and pressure of the cooling water. The sum of these loads plus the friction of the axles in their boxes makes up the sum-total of work to be done; this work must be given out from the locomotive drivers. It all reappears in the form of draw-bar stress, and its value is shown by the traction dynamometer. An elaborate system of piping (not shown in figures) provides for the circulation of the cooling water for the brakes at whatever point along the length of the foundation they may be located.

45. The Traction Dynamometer.—The vibrating character of the stresses to be measured makes the design of the traction dynamometer a matter of some difficulty. The dynamometer of the original plant consisted of an inexpensive system of levers attached to a heavy framework of wood, the vibrations being controlled by dashpots. In the present construction wood as a support is entirely abandoned and a massive brick pier, well stayed with iron rods, has been substituted. The dynamometer itself (*B*, Figs. 65 and 66) consists of the weighing-head of an Emery testing-machine, the hydraulic support of which is capable not only of transmitting the stress it receives, but also of withstanding the rapid vibrations which the draw-bar transmits to it. The apparatus is of 30,000 pounds capacity.

In view of the enormous force which a locomotive is capable of exerting it would appear, at first sight, that an error of 50 or even 100 pounds in the determination of draw-bar stresses would be of slight consequence, and that great accuracy in this matter is not required. Under some conditions this conclusion is correct, but under others it is far from true. The work done at the draw-bar is the product of the force exerted multiplied by the space passed over; if the force exerted be great and the speed low, a small error in the draw-bar stress is not a matter of great importance; but if the reverse conditions exist—if the speed be high and the draw-bar stress low—then it is absolutely necessary that the draw-bar stress be determined with great accuracy. Moreover, high speeds necessarily involve low draw-bar stresses. A locomotive which at 10 miles an hour may pull 12,000 pounds will have difficulty, when running 60 miles per hour, in maintaining a pull of 2500 pounds. These conditions have prompted the Purdue authorities to make extraordinary efforts to secure accurate measurements at the draw-bar, and they serve as a sufficient justification of the heavy expenditure involved in the purchase of the Emery machine.

As is well known, the arrangement of the hydraulic support of the Emery testing-machine permits the weighing-scale to be at any convenient distance from the point where the stresses are received. Figs. 65 and 66 show only the receiving end of the apparatus. The draw-bar connects with this apparatus by a ball-joint, which leaves its outer end free to respond to the movement of the locomotive on its springs. A threaded sleeve allows the draw-bar to be lengthened or shortened for a final adjustment of the locomotive to its position upon the supporting wheels; and finally, to meet the proportions of different locomotives, provision is made for a vertical adjustment of the entire head of the machine upon its frame.

46. The Superstructure.—Figs. 67 and 68 show the arrangement of floors. The "visitors' floor" (Fig. 68) and the fixed floors adjoining are at the level of the rail. The open space over the wheel-foundation is of such dimensions as will easily accommodate an engine having a long driving-wheel base, movable or temporary floors being used to fill in about each different engine, as may be found convenient. The temporary flooring shown is that employed for the locomotive Schenectady No. 1.

The level of the "tender-floor" is at a sufficient height above the rail to serve as a platform from which to fire. At the rear is a runway leading to the coal-room, the floor of which is somewhat lower than the tender floor. A platform scale is set flush with the floor at the head of the runway. During tests the scale is used for weighing the coal which is delivered to the fireman.

The feed-water tank, from which the injectors draw their

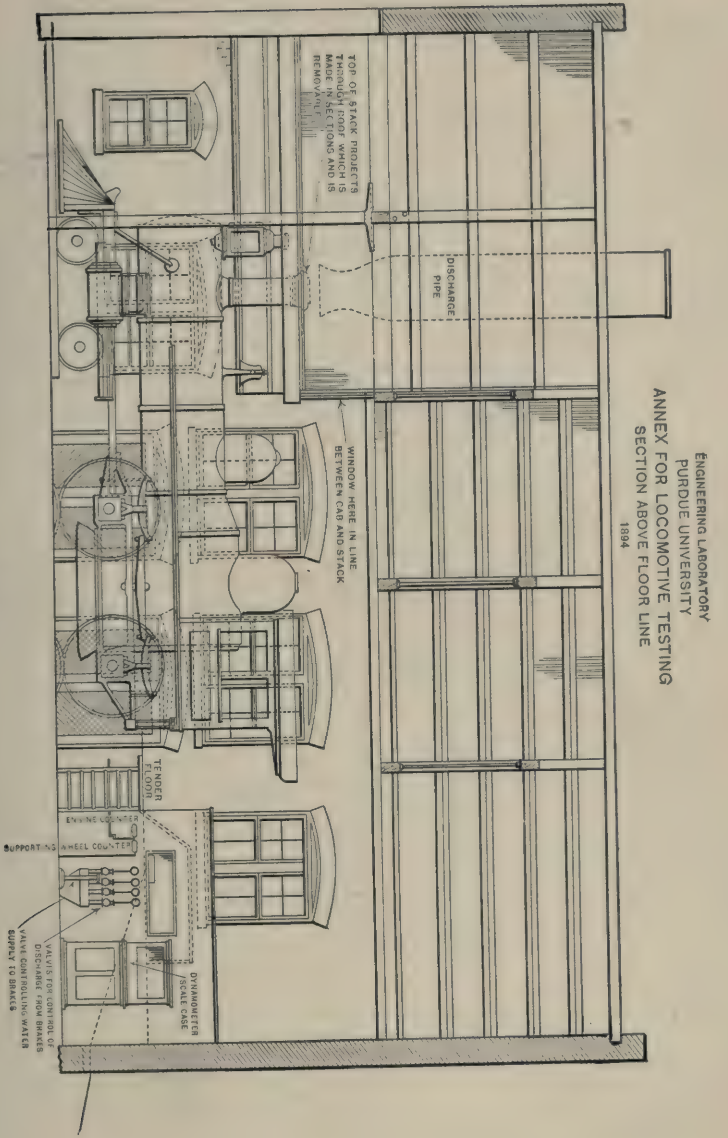
ENGINEERING LABORATORY
PURDUE UNIVERSITY
ANNEX FOR LOCOMOTIVE TESTING
SECTION ABOVE FLOOR LINE
1894
TOP OF STACK PROJECTS THROUGH ROOF WHICH IS MADE IN SECTIONS AND IS REMOVABLE
DISCHARGE PIPE
WINDOW HERE IN LINE BETWEEN CAB AND STACK
TENDER FLOOR
ENGINE COUNTER
SUPPORTING WHEEL COUNTER
VALVES FOR CONTROL OF DISCHARGE FROM BRAKES
VALVE CONTROLLING WATER SUPPLY TO BRAKES
DYNAMOMETER SCALE CASE

Fig. 67.

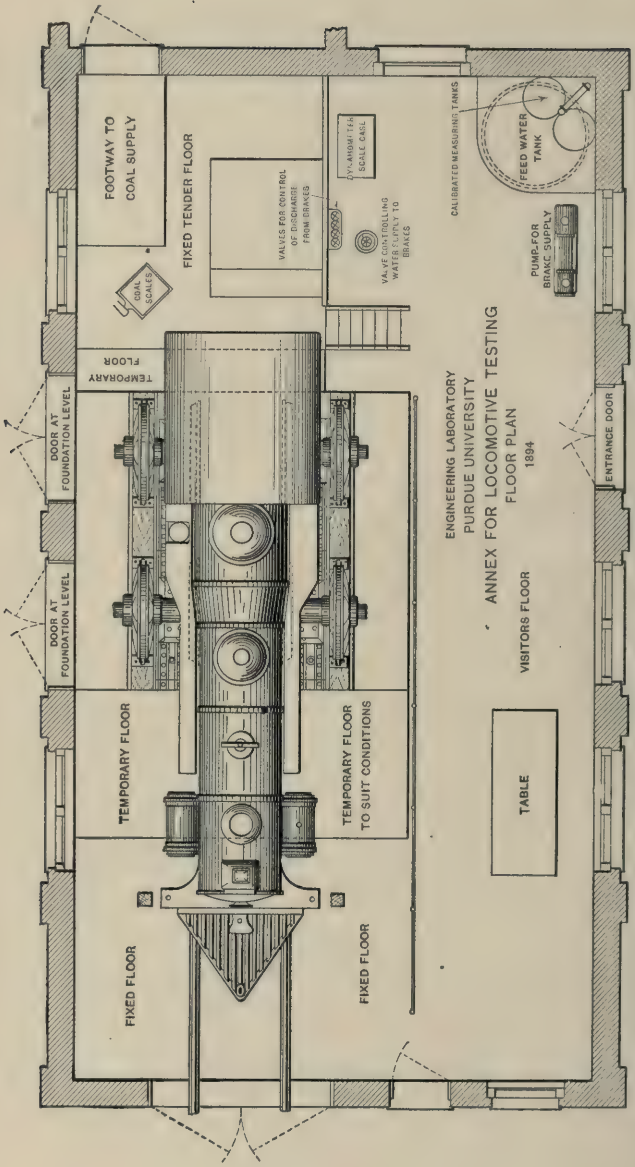
FOOTWAY TO COAL SUPPLY
FIXED TENDER FLOOR
COAL SCALES
VALVES FOR CONTROL OF DISCHARGE FROM BRAKES
DYNAMOMETER SCALE CASE
VALVE CONTROLLING WATER SUPPLY TO BRAKES
CALIBRATED MEASURING TANKS
FEED WATER TANK
PUMP FOR BRAKE SUPPLY
TEMPORARY FLOOR
DOOR AT FOUNDATION LEVEL
DOOR AT FOUNDATION LEVEL
ENGINEERING LABORATORY
PURDUE UNIVERSITY
ANNEX FOR LOCOMOTIVE TESTING
FLOOR PLAN
1894
ENTRANCE DOOR
VISITORS FLOOR
TEMPORARY FLOOR
TEMPORARY FLOOR TO SUIT CONDITIONS
TABLE
FIXED FLOOR
FIXED FLOOR

FIG. 68.

supply, is shown in the lower right-hand corner of Fig. 68. Above this supply-tank are two small calibrated tanks so arranged that one may be filled while the other is discharging.

The steam-pump shown on the visitors' floor is for the purpose of supplying water under pressure to the friction-brakes which load the engine.

The conditions under which the engine is operated are at all times within the control of a single person, whose place is just at the right of the steps leading to the tender-floor. From this position he can see the throttle and reverse-lever and observe all that goes on in the cab. At his right is the dynamometer scale-case, wherein is shown the load at the draw-bar; in front are the gages giving the water-pressure on the brakes; and under his hand are the valves controlling the circulation of water through the brakes.

No attempt has been made in these drawings to show small accessory apparatus, neither does it seem necessary to give an enumeration of such details.

47. The Building.—Fig. 69 presents several views of the locomotive building. The entrance-door, which opens upon the visitors' floor, is shown in the south elevation, It is approached from the general laboratory, 45 feet away.

The north and west elevations show the roof-construction, whereby the upper end of the locomotive stack is made to stand outside of the building. The roof-sections shown may be entirely removed and a door in the cross-wall, which extends between the removable roof and the main roof, provides ample height for the admission of the locomotive to the building. A window in this door (Fig. 68) serves to give the fireman a clear view of the top of the locomotive stack from his place in the cab, a condition which is essential to good work in firing. Above the stack is a pipe to convey the smoke

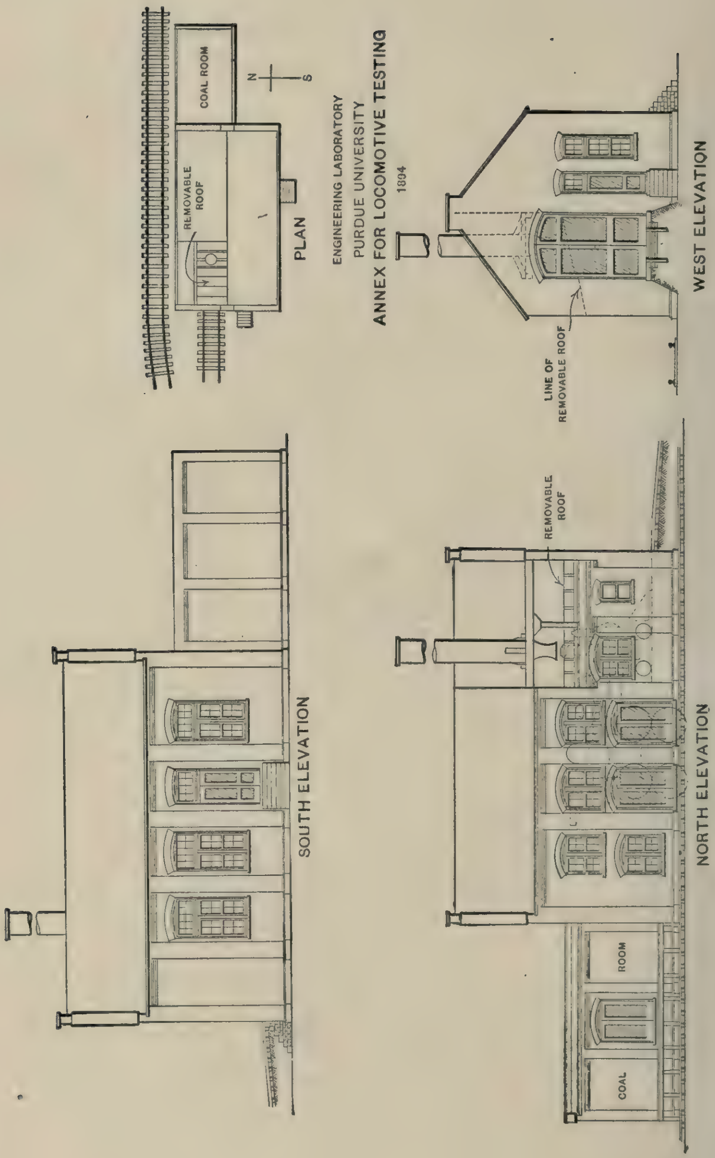
COAL ROOM
N
S
REMOVABLE ROOF
PLAN
ENGINEERING LABORATORY
PURDUE UNIVERSITY
ANNEX FOR LOCOMOTIVE TESTING
1894
LINE OF REMOVABLE ROOF
WEST ELEVATION
SOUTH ELEVATION
REMOVABLE ROOF
NORTH ELEVATION
COAL
ROOM

Fig. 69.

clear of the building. To meet a change in the location of the stack this pipe may be moved to any position along the length of the removable roof.

The plan of the building (Fig. 69) shows the arrangement of tracks for the locomotive and of those used for supplying coal.

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